January 2012

Integration Of Small Unmanned Aircraft Systems Into Precision Agriculture: Putting The Power Of Remote Sensing Into The Hands Of Farmers

Jeremy Richard Smith

INTEGRATION OF SMALL UNMANNED AIRCRAFT SYSTEMS INTO PRECISION AGRICULTURE: PUTTING THE POWER OF REMOTE SENSING INTO THE HANDS OF FARMERS

by

Jeremy R. Smith
Bachelor of Science, Brigham Young University, 2010

A Thesis

Submitted to the Graduate School

of the

University of North Dakota

in partial fulfillment of the requirements

for the degree of

Master of Science

Grand Forks, North Dakota
May
2012

This thesis, submitted by Jeremy R. Smith in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

____
Chairperson, Santhosh K. Seelan

____
Bradley C. Rundquist

____
Joseph J. Vacek

This thesis meets the standards for appearance, conforms to the style and format requirements of the Graduate School of the University of North Dakota, and is hereby approved.

____
Dean of the Graduate School, Wayne Swisher

____
Date

PERMISSION

Title	Integration of Small Unmanned Aircraft Systems into Precision Agriculture: Putting the Power of Remote Sensing into the Hands of Farmers
Department	Space Studies
Degree	Master of Science

In presenting this thesis in partial fulfillment of the requirements for a graduate degree from the University of North Dakota, I agree that the library of this University shall make it freely available for inspection. I further agree that permission for extensive copying for scholarly purposes may be granted by the professors who supervised my thesis work or, in their absence, by the chairperson of the department or the dean of the Graduate School. It is understood that any copying or publication or other use of this thesis or part thereof for financial gain shall not be allowed without my written permission. It is understood that due recognition shall be given to me and to the University of North Dakota in any scholarly use which may be made of any material in my thesis.

Signature __Jeremy Smith________________________

Date ___18-May-2012_______________________

TABLE OF CONTENTS

LIST OF FIGURES vii

LIST OF TABLES x

ACKNOWLEDGEMENTS xi

ABSTRACT xiii

CHAPTER

1. INTRODUCTION 1

1.1. Remote Sensing in Agriculture 1

1.2. The Basics of Remote Sensing in Agriculture 2

1.3. Uses of Remote Sensing in Agriculture 4

1.4. Limitations of Satellite Remote Sensing for Agriculture 5

1.5. The Role of Unmanned Aircraft Systems in Agriculture 7

1.6. Objectives of this Study 9

2. TECHNICAL LITERATURE REVIEW 12

2.1. Brief History of Unmanned Aircraft Systems 12

2.2. The Many Uses of Unmanned Aircraft Systems 15

2.3. Development of Unmanned Aircraft Systems in Agriculture 16

3. LEGAL LITERATURE REVIEW 22

3.1. What is an Unmanned Aircraft System 22

3.2. Recreational Aircraft vs. Unmanned Aircraft Systems 23

3.3. Current Laws and Regulations 24

3.4. Certificate of Authorization 26

4. METHODS 29

4.1. Choosing an Unmanned Aircraft 29

4.1.1. Lightweight, Small and Portable 31

4.1.2. Inexpensive 34

4.1.3. Easy to Use 36

4.2. The CropCam 36

4.3. Site Selection 39

4.3.1. Applying for Certificates of Authorization for Farmers' Fields 43

4.4. Camera Selection 49

4.4.1. Creating a NIR Point-n-Shoot Camera 51

4.5. Selection of the Acquisition Time for Data and Images 54

4.5.1. Satellite Image Data 55

4.5.2. AEROCam Data 57

4.5.3. CropCam Data 58

5. ANALYSIS AND RESULTS 61

5.1. Review of Flying Days, Post-Processing, and Results 61

5.1.1. Flying Day 1 – 18 September 2010 61

5.1.2. Flying Day 2 – 11 June 2011 63

5.1.3. Flying Day 3 – 16 June 2011 70

5.1.4. Flying Day 4 – 17 July 2011 72

5.1.5. Flying Day 5 – 6 August 2011 73

5.1.6. Flying Day 6 – 8 September 2011 77

6. CONCLUSIONS 79

6.1. Choosing the Correct Flying Height for Future Missions 79

6.2. Issues with Unmanned Aircraft Systems Using Point-n-Shoot Cameras 87

6.2.1. Images are Not Georeferenced 87

6.2.2. Image Mosaic and Overlap Issues 88

6.3. Image Comparison between the Three Different Platforms 89

6.4. Analysis of Water Damage and Planter Issues through Image Comparison 90

6.5. Legal conclusions 99

7. FUTURE WORK 103

APPENDIX 104

REFERENCES 110

LIST OF FIGURES

Figure Page

1. Example of the Vegetation Red Edge Shift 4
2. Ryan Firebee Shortly After Being Released From the Belly of a B-26 14
3. NASA's Pathfinder Plus UAS over Kauai, HI 18
4. Cloud Cover Obstructing the View of the Hawaiian Coffee Fields 20
5. UND's Scan Eagle and Pneumatic Launcher 32
6. The Hand Launching of the CropCam 33
7. CropCam in Gun Case 34
8. The CropCam Unmanned Aircraft System 37
9. Screenshot of the Horizon GCS Software 38
10. Small Scale view of the Flying-S CoA 41
11. Large Scale view of the Flying-S CoA 42
12. Small Scale view of the Crookston CoA 45
13. Large Scale view of the Crookston CoA 46
14. Small Scale view of the Grafton CoA 47
15. Large Scale view of the Grafton CoA 48
16. Pentax Optio A40 12 MP 49
17. CCD Sensitivity with Accompanying EM Regions 52
18. NIR Filter Blocking Visible Light and Allowing NIR light to Pass to CCD 53
19. Canon S70 7MP 53

20. Landsat 5 image, 28-June-2011 56

21. Flying Heights for CropCam Flying Days 59

22. Camera Pods for Canon S70 66

23. Broken Camera Pod with Camera Still Attached to the Base of the Pod 66

24. Flight 4 Image Mosaic with Planned and Actual Flight Paths 69

25. Flight 1 Image Mosaic 72

26. Flight 2, 1,000 ft AGL 75

27. Flight 2, 1,000 ft AGL, NIR 76

28. Flight 1, 1,000 ft AGL 78

29. Visual Line of Sight of the CropCam at 400 ft 80

30. Flying Heights and Images 82

31. About 50% Forward Overlap for 400 ft AGL Images 84

32. Forward and Return Legs of the 400 ft AGL Flight Path 85

33. About 80% Forward Overlap at 1,000 ft AGL 86

34. About 80% Forward Side Overlap at 1,000 ft AGL 86

35. Landsat Image 93

36. AEROCam Image 93

37. CropCam Image 93

38. Landsat CIR Image 94

39. AEROCam CIR Image 94

40. CropCam NIR Image 94

41. Landsat Water Damage 96

42. AEROCam Water Damage 96

43. CropCam Water Damage 96

44. CropCam Close-up 97

45. AEROCam Close-up... 97

46. CropCam Water Damage Area.. 98

47. Individual Rows... 99

LIST OF TABLES

Tables Page

1. Specifications of the CropCam, Scan Eagle and Raven B 30

2. CropCam Specifications 37

3. List of Satellite Images for this Study 55

4. List of Manned Aircraft Images for this Study 57

5. List of CropCam Images for this Study 60

6. Images Used for Image Comparison 89

ACKNOWLEDGEMENTS

The author would like to thank and express deep appreciation to all the members of the advisory committee. Dr. Santhosh Seelan spent generous amounts of time and provided important guidance to help this project go in the right direction. He also providing significant insight, made sure things were done correctly and most importantly, made sure my wife and I were comfortable in Grand Forks. Dr. Bradley Rundquist provided valuable direction with the image processing and was influential in helping me obtain a small grant to purchase the cameras needed for this study. Dr. Joseph Vacek was instrumental in guiding me through the tricky legal climate of small unmanned aircraft systems. Without his help it would have been difficult to see the forest through the trees.

The author would also like express deep gratitude to John Nordlie and Charles Taylor. This project would not have been possible without their extensive understanding of the unmanned aircraft used during this study. John provided a wealth of information during the project that helped guide the decision making. Charles' vast understanding of the mechanics of the unmanned aircraft, current regulations and how to fly the aircraft were critical to the success of the study.

DEDICATION

To my three beautiful girls: Judipa, Lilē'ahona, and Snuggles.

ABSTRACT

The rapid emergence and advancement of small unmanned aircraft systems (sUAS) has made it possible for their incorporation into modern agriculture. Satellite imagery has been used in the past to increase yields and profits while simultaneously decreasing chemical use and environmental damage. However, satellite imagery has some limitations in regards to agriculture that sUAS has the potential to supplement and correct. This study will present the technical and legal integration of sUAS into private agriculture in the United States. Multiple flights were conducted at various altitudes to understand the lowest possible altitude for safe and useful image recovery. A comparison of satellite, manned aircraft, and sUAS was conducted to determine the relative usefulness of sUAS in contrast to other proven remote sensing platforms for crop analysis. A review of the current sUAS regulations and a possible solution for speedy and safe integration will also be presented.

CHAPTER 1

INTRODUCTION

1.1 Remote Sensing in Agriculture

The development of agriculture was one of the first major steps in the advancement of human civilization. The ability to cultivate, forecast, store and prepare crops set humans apart from the rest of the animal kingdom. Since those early beginnings, man has devised many ingenious methods to increase agricultural yields from one year to the next. Advances in technology that include irrigation, fertilization and pest control helped to amplify the basics of agricultural progressivism; reducing inputs and increasing outputs.

Our modern age, however, has awakened us to a greater understanding of the detrimental effects that our artificial, industrial-style agriculture has on the global environment (Botkin and Keller, 2010). This greater understanding has led to tweaks and additions to the basics of agriculture. Although decreasing inputs and increasing outputs continues to be the theme of modern agriculture, a rising influence of environmental awareness is becoming more apparent. This new goal has shifted agriculture over the last two decades to a more site-specific, within-field crop management system called precision agriculture (Pinter, 2003).

Precision agriculture combines global positioning systems (GPS), geographical information systems (GIS), yield monitors, micro-computers, remote sensing and many other advanced technologies to reduce inputs and increase outputs (Zhang *et al.*, 2009).

Satellite remote sensing, in recent years, has proven to be an extremely useful tool in allowing farmers to monitor their crops, adjust their inputs, and increase their outputs while simultaneously improving the local environment (Seelan *et al.*, 2007).

1.2 The Basics of Remote Sensing in Agriculture

Remote sensing is the acquisition of information about an object or phenomenon, without making physical contact with the object (Campbell, 2002). Although this definition can refer to anything from a camera, satellite, or even the human eye, the term has traditionally been used in reference to the use of aerial and space sensor technology to detect and classify objects on the Earth's surface (Jensen, 2007).

There are two major types of remote sensing, passive and active. Passive sensors detect natural energy either emitted by or reflected off of the object of interest. Sunlight, for example, is the most common source of energy for passive remote sensing. In the simplest sense, sunlight reaches the Earth’s surface after traveling millions of miles, reflects off the object of interest, and is captured by the sensor. The sensor then digitizes that captured energy into an image or another form of data to be used for later analysis with geospatial software.

Active remote sensing is slightly different in that it incorporates the emission of energy from the sensor. The energy emitted by the sensor reflects of the object or surface of interest. The time it takes for that energy to return is used to calculate a distance between the object or surface of interest and the sensor. Active remote sensing is very useful in creating very specific topographic maps and other three-dimensional products. The two most commonly used forms of active remote sensing are radio detection and ranging (RADAR) and light detection and ranging (LiDAR). Although, active remote sensing is a very useful tool for a variety of tasks and studies it is rarely used in agriculture.

The unique properties of green leaf plants make remote sensing a particularly useful tool for agriculture. These types of plants have a low reflectance and transmission in the visible region (400 – 700 nm) of the electromagnetic (EM) spectrum while simultaneously emit a high reflectance and transmission in the near-infrared region (NIR) (700 - 1,300 nm). This unique spectral signature creates what is referred to as the 'vegetation red edge shift'. Figure 1 exhibits an example of a typical graph representing the shift in the red edge when a plant is under stress. During plant stress the NIR reflectance decreases and the red edge begins to shrink, shift toward shorter wavelengths, or disappear entirely (Pinter, 2003). If the area of interest is recorded in a rhythmic manner, the shift in the red edge can be detected even when the plants may still look green and healthy to the naked eye. This valuable information can help farmers identify problems sooner, mitigate these problems in a more rigid, scientific, and productive manner, and can facilitate the decrease of inputs and the increase of outputs.

Vegetation indices (VIs) are another important tool farmers can use to monitor crop canopies that are more complex than a single plant measurement (Jensen, 2007). A VI is a quantitative measure of biomass or vegetation vigor. It is created by the combination, addition, division, or multiplication of several spectral bands to produce a single number that represents the amount or vigor of the vegetation. There is a wide variety of VIs, however, the most common VIs for agriculture include the ratio vegetation index (RVI) and the normalized difference vegetation index (NDVI) (Weigand *et al.*, 1991). Using the VI equations, farmers can systematically monitor uneven patterns of growth within a field throughout the growing season.

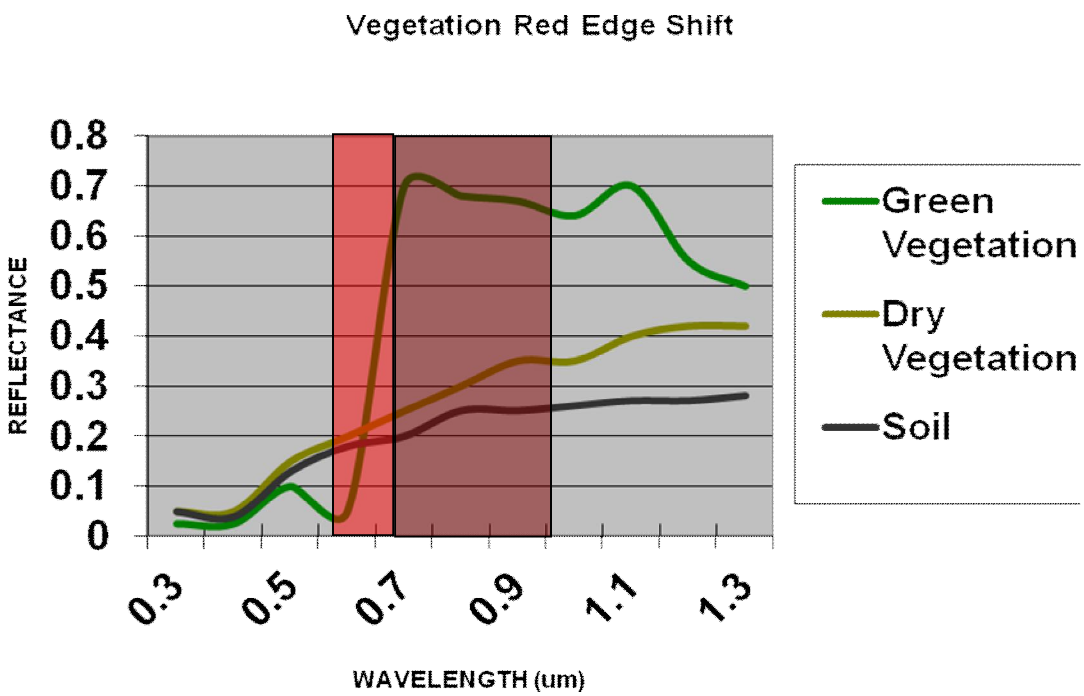


Figure 1. Example of the Vegetation Red Edge Shift

1.3 Uses of Remote Sensing in Agriculture

Remote sensing is increasingly being used by farmers as another tool in their precision farming tool bag (Pinter *et al.*, 2003; Seelan *et al.*, 2007). Farmers and ranchers are both using satellite data to increase yields and profits, decrease chemical input, and save money. There are many examples and the results are quite impressive. A complete description of the many uses of remote sensing in agriculture is beyond the scope of this study. However, there are some notable examples that include satellite image data used to monitor wheat on a weekly basis throughout the growing season, statistical information for stress detection, images that helped with zoning for variable-rate application of nitrogen, and images that provided important evidence for spray drift damage assessment (Seelan *et al.*, 2003). There are a wide variety of uses for remote sensing in agriculture and the results are impressive.

1.4 Limitations of Satellite Remote Sensing for Agriculture

Although remote sensing has proven to be an extremely useful technology for the monitoring of crops throughout the growing season, there are many limitations of satellite remote sensing in regards to agriculture. These limitations, in the present and near-future, are uncorrectable and cause gaps in the usefulness of satellite remote sensing for agriculture. This is where unmanned aircraft systems (UAS) have an opportunity for integration and can assert itself as an integral part of the farming of the future. Unmanned aircraft has the potential to fill the gaps and supplement the usefulness of satellite remote sensing for agriculture.

The first major issue for farmers is the lack of control. Satellites are multi-million dollar machines that are constructed and controlled by only a handful of organizations and agencies. The spatial, spectral, and temporal needs of an agricultural project are always project-specific and having only a handful of satellites to work with that provide cheap-to-free data can be troublesome. The farmer has no control over the type of images he receives. Most satellite images arrive in huge files that require multiple layers of decompression. Many computers, especially if they are old, will require upwards of an hour of download and decompression time before the satellite image can be displayed. Also, many satellite images arrive in file formats that require special geospatial software to correctly view and interpret. These images come in whatever spatial and spectral resolutions the particular satellite produces. The farmer has no control over these features and experience has shown that it may require the use of multiple platforms to get all the data that is needed for a particular study (Seelan *et al.*, 2003).

Another major issue, specifically for agriculture, is temporal resolution. Satellites are locked into predictable orbits and controlled by only a handful of organizations. Each satellite will image the same area on a predictable time and date, which is called temporal resolution. Although it is no longer operational, Landsat 5 provided valuable images for agricultural monitoring and research with a temporal resolution of 16 days (NASA, 2011). Landsat 5 has proven to be an extremely valuable asset for studies that require data over the course of many years. However, for farmers, they have different requirements when it comes to satellite imagery. It has been found that for data to be useful in agriculture it must be provided on short intervals and as near real-time as possible (Seelan *et al.*, 2003; Grenzdorffer *et al.*, 2009). With a satellite like Landsat 5 the best a farmer can receive is only two images of his fields per month. This, of course, is completely dependent upon the weather.

The majority of remote sensing satellites are passive and clouds greatly obstruct the view of the sensors due to the scattering of light. In climates where there is frequent cloud cover, cloud-free images can be hard to capture. If this is the case, satellites can become rather useless to a farmer as described in the following representative scenario.

A farmer wants an image of his fields. He checks the times for the Landsat 5 flyover and determines that his fields will be imaged on June 1st. When that day arrives there is complete cloud cover and his Landsat 5 images are useless. He is forced to wait 16 days for the next pass. When June 17th arrives it is another cloudy day and the images are again useless. He is again forced to wait another 16 days for Landsat 5 to return and image his fields. When July 3rd finally arrives the sky is clear and useful images are captured. However, the farmer has now missed the climax of the spraying season and most of the issues that could have been prevented or changed have already passed. The lack of control in this situation is apparent.

The above situation, although a fictional account, is not far from the truth. It is quite common for farmers to only collect two or three usable Landsat 5 images of their fields throughout the growing season and the dates of these useable images are sporadic. Cloud cover greatly reduces the usefulness of satellite remote sensing in agriculture and provides a limitation for which UAS can provide an alternative.

1.5 The Role of Unmanned Aircraft Systems in Agriculture.

Most of the issues concerning satellite remote sensing in agriculture revolve around that fact that the farmer has no control. He receives a product and if it does not suit his needs, he is out of luck, there is no other alternative. This is where UAS can play a significant role by patching the gaps of satellite remote sensing in agriculture. One of the major benefits is that UAS puts the power of remote sensing into the hands of the individual farmer. Setting aside the current rules and regulations, which will be discussed in the following pages, UAS has the capacity to take pictures almost anywhere, anytime, and in any way the user desires. The farmer has the ability to choose how and when he uses remote sensing technology in his particular practice.

Another of the major benefits of UAS is that it allows farmers to capture images under the cloud canopy. As long as there is sufficient sunlight to break through the cloud canopy and reflect off the object of interest to the sensor aboard the aircraft, images can be collected. Days when satellites would capture only cloud-filled images, UAS can collect the required data below the cloud canopy. Another benefit is that UAS has a spatial resolution many magnitudes greater than most modern satellites. CropCam (2011) reports that the spatial resolution of its aircraft and sensor is around 15 cm; about 44,000 times greater than average satellites and 44 times greater than the most advanced satellite in use today. With this type of resolution it might soon be possible to make changes and modification throughout the growing season by row or column and not just by sections or areas.

Another major benefit of UAS is that once the airframe is acquired the costs are minimal. Many farmers have been using satellites images through the use of agencies and programs that provide free data (Seelan, 2007). However, if a farmer desires high resolution satellite images, it will most likely come at a significant cost. UAS allows the farmer access to remote sensing technology without any outside intervention or additional cost. Another similar benefit is that the farmer becomes his own data center. After years of capturing images of the same fields, he can review the images side-by-side and identify trends and patterns within his fields that will help him make better decisions in the future.

UAS, of course, is not a panacea for all remote sensing problems. There are understandably a few accompanying disadvantages. Much of the current UAS technology is new and unrefined. The farmer will undoubtedly have to do his own repairs and maintain proficiency in the technology. Also, many of the small UAS do not georeference or mosaic the images they capture. The required post-processing can greatly increase the time the farmer has to spend before he can correctly interpret his images. Most importantly, the legality of operating UAS in the national airspace (NAS) is still in question. UAS operating in the NAS, under the current regulations, are not allowed for commercial purposes. This poses an obvious setback for a private farmer wishing to use UAS for commercial purposes. The disadvantages of UAS for agriculture will be examined and thoroughly discussed through this study.

1.6 Objectives of the Study

The purpose of this study is to analyze the technical and legal aspects of the integration of small, inexpensive, and easy to use unmanned aircraft into private agriculture in the United States. A review of the current legal climate with regards to UAS will be conducted to better understand the possibility of privately owned and operated UAS in agriculture. Suggestions for future legal directions will be recommended as a result of data collected during this study. Satellite, manned aircraft and UAS images, over a specific agricultural site in northeastern North Dakota, will be captured and compared to determine the relative usefulness of UAS in contrast to other proven remote sensing platforms in crop analysis and application. To meet the primary goal, the study has been carried out with the specific objectives:

- Identify and describe the current legal climate regarding the integration of UAS into the NAS.
- Provide a description of possible regulatory solutions for the integration of UAS into the NAS.
- Capture and analyze images collected with three different platforms on roughly the same dates; satellite, manned aircraft, and unmanned aircraft.

- Conduct flights with a small UAS to identify the opportunities and limitations of this technology as it applies to the premise of a private farmer owning and operating the aircraft.

The first objective is designed to better understand the legal situation surrounding the possible integration of unmanned aircraft into modern precision agriculture. The current rules and regulations for unmanned aircraft operating in the NAS are quite fluid and open for much interpretation. An in-depth analysis of the current legal climate and future projections will help determine the feasibility of a private farmer owning and operating his own small unmanned aircraft.

The second objective is to determine, after completing a season of test flights, some possible regulatory solutions that will help speed up the integration of small UAS into the NAS. The UAS industry is about ready to explode with growth. Hundreds of companies are already designing and testing new unmanned aircraft to be used for various purposes. However, the lack of a strong regulatory environment is holding back this technology from its full economic potential. New regulations and rulings need to be created and implemented in a timely manner to help spur the growth of this industry.

The third objective is to help determine the relative usefulness of unmanned aircraft imagery for the private farmer. Satellite and manned aircraft imagery have already been shown to be useful tools in precision agriculture. This section will help determine of usefulness of unmanned aircraft imagery when compared to its tried-and-proven counterparts.

The fourth and final objective is to fly a small unmanned aircraft over a farmer's field. The field studies will be used to identify any limitations that might cause UAS technology to not be successfully integrated into precision agriculture. This objective will also assist in the identification of opportunities that UAS might present in helping farmers achieve their goals of lower inputs and greater outputs.

CHAPTER II

TECHNICAL LITERATURE REVIEW

2.1 Brief History of Unmanned Aircraft Systems

The history and development of unmanned aircraft coincides greatly with the history and development of manned aircraft. However, many of these early unmanned aircraft were developed only as models that were designed to test the airworthiness of a manned aircraft. These aircraft were mostly a means to an end and not a finished product (Peterson, 2006). Although the actual starting point of unmanned aircraft is open for debate, it is generally considered that it found its beginnings around the World War I era. The early unmanned aircraft of this period were essentially just flying bombs. There were no flight controls and the aircraft was designed to crash and explode after a certain pre-programmed period of flight. Although these unmanned aircrafts were very primitive in both design and flight control, they were the first real attempts at creating aircraft with mechanical autopilots (Chao *et al.*, 2009).

These early developments in autopilot technology were very raw. The aircraft simply flew a mechanically controlled, pre-determined flight path and lacked any kind of significant control or stabilization. With the advent of gyrostabalization by Elmer and Lawrence Sperry, radio control by Nikola Tesla, and the miniaturization of parts over time unmanned aircraft began to become more complex and assumed the role of a specialized technology (Newcome, 2004). However, the majority of unmanned aircraft continued to be developed as either flying bombs or target drones, not as pilot-less airplanes.

In 1922, the British Royal Navy began to realize the full potential of unmanned aircraft as actual aircraft and not just winged-missiles. The first remote-controlled flight was conducted on September 3, 1924 in Great Britain. The Royal Navy launched a craft that flew for 39 minutes and covered a range of 65 miles. This type of aircraft was never fully developed into a true UAS but rather assumed the role of a target drone. Although they were reusable, they were only reusable in the event that the gunner missed its target (Peterson, 2006).

The next major American step towards true UAS development occurred during the 1950s with the development of Ryan Aeronautical's Q-2 or Firebee. The Firebee is considered by many historians to be the first true unmanned aircraft system because it was self-propelled and controlled from the ground (Chao *et al*., 2009). The Firebee was first introduced in 1951 as a jet-powered gunnery target. The Firebee was carried to altitude on the belly of a B-26 (Figure 2). After it was released from its mounting on the bottom of the B-26, it was maneuvered by signals from a control box operated by an officer on the ground (Popular Mechanics, 1954). The Firebee program was very successful and led to an entire family of advanced target drones.

Major developments in unmanned aircraft technology continued during the Cold War after United States pilot Francis Gary Powers was shot-down over the Soviet Union (Peterson, 2006). This misfortune led to a reevaluation of the priorities of manned aircraft and a discovery of what could be accomplished using unmanned aircraft. The development of the premise of what we now call, “dull, dirty, and dangerous” missions was development (Curry *et al*, 2004). The hazards of manned military reconnaissance missions led to the development of high altitude long endurance (HALE) UAS to perform these dangerous missions. The Global Hawk and the Predator UAS are two very successful systems that were developed to serve the role of reconnaissance aircraft. Both aircraft have proven to be an overwhelming success in providing intelligence while keeping airman safely on the ground and out harm's way (Deptula and Marrs, 2009).

Figure 2. Ryan Firebee Shortly After Being Released from the Belly of a B-26. Source: San Diego Air and Space Museum.

The military has recently been interested in small UAS to fill the needs of real-time combat surveillance and communications. Small UAS, such as the Raven B and the RQ-7 Shadow, provide a lightweight, portable method for capturing real-time images and communications. These two aircraft have proven to be extremely valuable tools in keeping the American military one step ahead of rival forces.

As demonstrated by the brief history above, UAS technology in the United States has and continues to be driven by military applications. However, civilian applications are quickly becoming more desirable and accessible. UAS technology is now beginning to find its way into fields such as disaster monitoring, fire detection, pipeline and site inspection, traffic monitoring, mapping, movie production, and agriculture (Ritchie *et al*., 2008).

2.2 The Many Uses of Unmanned Aircraft Systems

During the past decade researchers have been using UAS for a wide variety of projects. The first steps in UAS research came as scientists and researchers began using UAS to monitor environmental phenomena that were previously completed using satellite imagery. In 2002, Aerosonde began demonstrating that its Aerosonde Environmental Observing Platform UAS had the ability to conduct professional environmental monitoring reconnaissance. The Aerosonde UAS had a wingspan just under ten feet, a maximum weight of 33 pounds, and an endurance that could extend beyond 30 hours. The company demonstrated in May of 2002 that its small UAS could conduct dangerous missions over the arctic and collect data about pressure, temperature, humidity, horizontal winds, and capture images to help determine ice sheet variations (Holland *et al*., 2002).

Foresters have begun to experiment with UAS as a tool that can be used in fighting forest and brush fires. UAS are valuable tools for dangerous missions because they can be put into hazardous situations, like a wildfire, without the risk of loss of life. Casbeer (2005) has shown, using mathematical models, how UAS can be used to monitor the spread of forest fires. Forest fires do not spread out in a uniform manner. Instead, many outside factors cause fires to spread in unique patterns. Multiple unmanned aircraft can be used in tandem to monitor the edges of the flames and report the unique spread of the fire. This information would help those responsible for putting out the flames by giving them valuable real-time information and better decision making abilities.

Bendea *et al.* (2007) demonstrated that by using a low-cost, mini UAS, archaeologists could map important archaeological sites and digs. Using a prototype UAS called the 'Pelican', the researchers were able to use a standard point-n-shoot digital camera to image an archaeological dig site. They were able to make an accurate map using the images and geospatial software. This study was continued by Verhoeven (2008) when he discovered hidden archaeological evidence by using a modified point-n-shoot camera to image in the NIR range. The modified point-n-shoot camera produced images that helped the researchers uncover remnants of ancient Roman walls that were buried beneath layers of sediment.

It quickly became apparent that UAS could be a reliable tool for accurate mapping. Everaerts (2008) demonstrated that there are many stable, small unmanned airframes that could serve as reliable means of aerial mapping. This research was followed up by Jensen *et al.* (2009) when they used a built-from-scratch UAS to capture images that they later georeferenced and stitched together to form an accurate picture of a larger area. These demonstrations of accurate mapping have opened the door for the integration of small UAS into modern precision agriculture.

2.3 Development of Unmanned Aircraft Systems in Agriculture

Many other countries quickly saw the value of UAS in agriculture and other environmental endeavors and began efforts to incorporate this new technology. The United States, however, has virtually delegated all UAS use for military purposes only. In 2007, it was estimated that more than 80% of all UAS technology in the United States was used by the military and the trend continues today (UAS, 2007). However, during the last few years, significant strides have been made in preparing this technology for the private sector. Many companies have begun testing and engineering a wide variety of UAS; everything from ‘flying insects’ to the jet-sized Global Hawk (Nebiker *et al.*, 2008). The wide variety of shapes, sizes, prices, and uses means that there is a great possibility that one particular UAS will be a good fit for private agriculture.

The majority of agricultural remote sensing has been satellite based. In recent decades, however, the abundance of multispectral airborne cameras has caused a rapid use of airborne remote sensing (Nebiker *et al.*, 2008). This development has the potential to trickle down to unmanned aircraft. This section will focus on some of the major developments of UAS in agriculture and the review will help form a basis for the discussion of UAS in agriculture.

One of the first major steps of UAS in agriculture came in 2001. NASA, along with researchers from many different universities, began conducting coffee field ripeness studies in Hawaii using NASA's Pathfinder Plus UAS (Herwitz *et al.*, 2002). The Pathfinder Plus UAS is an unique aircraft because of its ability to stay aloft for days, weeks, and possibly even months at a time. The unmanned aircraft is essentially a flying wing that is covered with solar panels (Figure 3). These panels store energy in batteries that allow the aircraft to stay aloft and continue operating during the night. The Pathfinder Plus is also distinctive in that it moves at an airspeed of only 15 to 20 mph. Its pitch is controlled by the use of tiny elevons on the trailing edge of the wings. All turns and yaw controls are accomplished by slowing down or speeding up the motors on the outboard sections of the wings (NASA, 2008).

The priority of this study, however, was not the monitoring of the coffee fields. The main objective was to test the use of an unmanned aircraft system in the NAS with the moderation and approval of the Federal Aviation Administration (FAA). Although the coffee fields were an auxiliary study, the images produced were stunning. The images were comparable to satellite quality because of the high-spatial resolution and multispectral imaging (Herwitz *et al.*, 2002). This study also demonstrated the unmanned aircraft's ability to provide virtually real-time data, something that most remote sensing satellites cannot do.

Figure 3. NASA's Pathfinder Plus UAS over Kauai, HI.

Source: Dryden Flight Research Center.

This study was a successful in demonstrating the usefulness of UAS in agriculture. However, there are some major drawbacks in terms of a private farmer owning and operating a UAS of this type. The first issue is that the Pathfinder Plus is a massive aircraft. It has a 98-foot wingspan and requires the use of a paved runway for takeoff and landings (NASA, 2011). Its large size makes it very impractical, even for the typical farmer who is accustomed to storing massive farming equipment.

The second major issue is that the Pathfinder Plus is an expensive aircraft and requires special training to operate. NASA allotted US$8 million to fund two demonstration missions over a period of four years (Spaceref, 2001). There are many variations of the Pathfinder Plus aircraft but estimates of the cost per aircraft are around US$7 million (Astronautix, 1999). Also, the complicated design of both the airframe and internal components require specially trained pilots and engineers to accompany and control the aircraft while in flight. The high cost and special training requirements push NASA's Pathfinder Plus UAS out of the realm of feasibility for private agricultural use.

The third and last major issue is that the design of the Pathfinder Plus has many of the same limitations as satellite images in relation to agriculture. The very high loitering altitude of the Pathfinder Plus means that it is above the cloud canopy (Figure 4). Depending upon the weather, the aircraft would need to maneuver to another area or wait for the cloud cover to pass to obtain the required images. Although the Pathfinder Plus is capable of staying aloft for extended periods of time and produce stunning images the aircraft is extremely impractical for the average farmer.

These issues may have blocked the Pathfinder Plus from being a practicable tool for the average farmer but the foundation had been set in stone. It demonstrated that UAS has to capability to serve as a practical substitute for satellite remote sensing. Following this foundational study came an era of cost and size reduction, increased user-friendliness, and substantial practicality.

Figure 4. Cloud Cover Obstructing the View of the Hawaiian Coffee Fields.

Source: NASA Earth Observatory.

Many of these same researchers continued their UAS in agriculture research by using a small UAS instead of the massive Pathfinder Plus. They used this small UAS to capture images of a large commercial vineyard in California. Around 165 images were collected with a spatial resolution of around 20 cm (Johnson *et al.*, 2003). However, the study did not advance much further into the development and use of the data and images for practical agricultural use.

This foundational study was followed up by a period of research that aligned with the premise of the potential use of small UAS in agriculture (Grensedorffer *et al.*, 2009, Jensen *et al.*, 2009, Xiang and Tian, 2011, Hardin and Jensen, 2011). However, many of these studies were from a mechanical or electrical engineering point of view and little analysis of the agricultural use of the data and images was completed. The purposes of these studies were to test the mechanics of the aircraft or the sensor for remote sensing purposes.

This study will attempt to move beyond the mechanics of the aircraft and begin to investigate the interpretation of the images and data captured as well as discuss the many legal issues surrounding the actual application of this technology into everyday, private agricultural use.

CHAPTER III

LEGAL LITERATURE REVIEW

3.1 What is an Unmanned Aircraft System

Throughout the history of aviation many different types of crafts have been built to put objects and people into the sky. Many of these crafts are quite similar in size, shape, and function. This makes it hard to define where one type begins and the other ends. Within the genealogical tree of aviation it is rather difficult to identify the beginning of the branch of what we refer to as today as, “Unmanned Aircraft Systems”. Convoluting the situation even more is that there is still no consensus as to what the technology should be called. The FAA has began an effort to standardize the use of ‘unmanned aircraft system’, the media and general public continues to use the term ‘drone’, while the military tends to use ‘unmanned aerial vehicle’ (UAV) or ‘remotely piloted vehicle’ (RPV).

There are many reasons why the term ‘unmanned aircraft system’ is used by the FAA. ‘Unmanned aircraft’ is a reasonable choice of words because the machine is an aircraft that is pilot-less or unmanned. Second, the term ‘system’ is chosen for the purpose of emphasizing that the unmanned aircraft is not an independent entity but part of a larger system; one that has consistent human interaction. The UAS simply does not fly on its own, making decisions on the go. An entire system is involved for the aircraft to launch, fly, and land safely. Each UAS is unique, however, almost all include some kind of ground control station (GCS), pilot-control, observers, support staff, data links, communications, navigation equipment, and launch and recovery infrastructure (Johnson, 2003). It has been determined that emphasizing the 'system' aspect of the design is important to better help the general public understand that these aircraft are not autonomous robots out of some Hollywood action movie but that they are actually quite similar to manned aircraft in many aspects. For the purpose of this paper, the term unmanned aircraft system or UAS will be used to keep in stride with the terminology used by the FAA (FAA, 2012).

3.2 Recreational Aircraft vs. Unmanned Aircraft Systems

As discussed previously, it can be hard to determine what should be defined as a UAS. Taking a step backwards, the definition of ‘aircraft’ according to the FAA is, “a device that is used or intended to be used for flight in the air” (FAA, 2012). With a loose reading of this definition an aircraft could be everything from a folded piece of paper to a sub-orbital rocket-plane.

As will be discussed later, there is a need to delineate between recreational/hobby aircraft and true UAS. As UAS get smaller and easier to use, the line between what can be considered a recreational aircraft and what should be considered a UAS is blurred. The main reason that a differentiation needs to be me made is because different rules apply to these two different types of aircraft (FAA, 2012).

In 1981, the FAA issued an Advisory Circular entitled, “Model Aircraft Operating Standards”, more commonly known as AC 91-57. The purpose of this document was to, “outline and encourage voluntary compliance with, safety standards for model aircraft operators” (FAA, 1981). The circular does not address what types, dimensions, or any other features of the aircraft that are required to be designated an amateur recreational aircraft. It does request, however, that all model aircraft remain below 400 ft AGL, operate a sufficient distance from populated and noise sensitive areas, and give the right of way to full scale aircraft (FAA, 1981).

Due to the vague nature of the wording in AC 91-57 it is possible for a farmer to contend that as long as he flies his UAS under 400 ft that it should not be restricted by UAS regulations but should rather be considered a large amateur model aircraft with a camera attached. Although this argument is feasible, there is a general consensus that common sense will be applied to this situation and it is highly unlikely that anyone will be successful in persuading the FAA that this argument is valid (Vacek, 2011).

In response to the previous thought process, the FAA made an amendment to their original ruling, clarifying their stance on the issue. "The FAA recognizes that people and companies other than modelers might be flying UAS with the mistaken understanding that they are legally operating under the authority of AC 91-57. AC 91-57 only applies to modelers, and thus specifically excludes its use by persons or companies for business purposes" (FAA, 2007). With this clarification, it is highly unlikely that any person or company would be able to persuade a judge that they can use their UAS for commercial purposes and still be under the guidance of AC 91-57. This clarification, however, creates a rather impassable wall for farmers who desire to use UAS in their private farming practice. According to this clarification, a farmer would not be able to legally use a UAS in his private farming practice because he is using it for commercial purposes.

3.3 Current Laws and Regulations

The difficulty with the legality of using small-UAS in agriculture is centered on the fact that strict and adequately defined rules and regulations for operating UAS in the

NAS currently do not exist. There has been a patchwork of regulations issued on a general 24-month bases under the titles, “Interim Operational Approval Guidance.” These documents provide UAS operators with a set of regulations for UAS operations in the NAS. However, these documents are far from anything that could be called a standardized list of regulations. The last issued guidance came in March 2008 and is commonly known as 08-01. An addition to this guidance is expected in 2012, however, at the time of this writing it had not been released.

The Interim Operational Approval Guidance 08-01, “provides guidance to be used to determine if unmanned aircraft systems (UAS) may be allowed to conduct flight operations in the U. S. national airspace system (NAS)” (FAA, 2008). Anyone wishing to use UAS technology, this includes private farmers, must follow the guidance provided in this document. There are many major features of this document that are important for the theoretical introduction and use of UAS in modern precision agriculture by private farmers and a summarized analysis will follow.

The first and most important regulation outlined in 08-01 is that in order for a UAS to operate in the NAS it must have special authorization. There are two types of authorizations listed in 08-01. The first and the most viable option is a Certificate of Authorization (CoA) and the second is a Special Airworthiness Certificate. The Special Airworthiness Certificate will not be discussed in this study because it is typically delegated to companies wishing to test experiment aircraft. This type of approval is not the preferred method for a private farmer to gain clearance to use a UAS for agricultural purposes.

3.4 Certificate of Authorization

The most viable option for a farmer to legally conduct UAS flights over his cropland is to apply for and receive a CoA (Vacek, 2011). A CoA is a document that grants permission for the individual or organization to conduct specific operations, with a specific aircraft, within a specified area. Although the application and reception of a CoA is currently the only viable option, there are many issues surrounding this procedure that make it unattractive for the individual private farmer.

The first major hurdle is that under the regulations of 08-01 a CoA may only be issued to a public entity. This segregation includes blocks of military airspace, the U.S. Border Patrol, and about 300 other public universities, police departments, and government agencies (AP, 2012). There is no avenue for a private, for profit or non-profit, entity to gain access to a CoA. Although the situation is currently bleak for those wishing to use unmanned aircraft for a commercial purpose there is much hope for the future.

In February 2012, Congress passed a bill that requires the FAA to speed up the completion of a set of regulations that will govern the integration of small UAS into the NAS. The bill authorizes US$63.4 billion for the next four years, including US$11 billion towards the modernization of the air traffic control system. It also set a date for the completion of the small UAS regulations by 30th of Sept, 2015. This bill requires the FAA to provide military, commercial, and privately owned unmanned aircraft with expanded access to U.S. airspace. It also requires that the FAA submit a plan on how they propose to safely provide unmanned aircraft with expanded access by November

2012 (AP, 2012). With this added pressure from Congress, there is much hope that the FAA will finally complete the long awaited small UAS integration regulations.

The next major issue for a private farmer is that each individual CoA specifies a precise area in which the unmanned aircraft may operate. This requirement will be burdensome for the modern farmer because most farmers today have plots of land scattered all around their surrounding area. Gone are the days of the family farm located around the family house. Today, farmers rent and buy land all around their particular area. It is not uncommon for a farmer to have multiple plots of land miles from each other. If a farmer wanted to image all of his land he would have two options; either construct a giant airspace that covers all of his land or apply for multiple CoAs for each of his plots of land. The issue with the first is that the larger the airspace gets the more likelihood of the CoA application being rejected. The issue with the second option is that the CoA process is cumbersome and lengthy. Applying for multiple CoAs would be very time consuming. Another important factor related to this situation is that CoAs are only good for one year. They can be renewed after one year and then reapplied for after the second. Farmers typically have a full plate of agricultural duties and adding the monitoring of CoA statuses would not be ideal.

The last major hurdle is that UAS are a very new technology and the industry is still in its infancy. When discussing the integration of UAS into agriculture it is important to remember that famers are farmers, they are not aviation experts. Although many farmers have some aviation experience through aerial applicators, the vast majority will not have a deep understanding of the technical or legal aspects of UAS that would be required for their successful use in agriculture. For a farmer to seamlessly integrate this new technology there will be a steep learning curve. This will include new legal regulations, language, and proficiency in small unmanned aircraft technical systems.

The integration of UAS into the NAS is an important topic that will need to find resolution before the economic benefit of UAS technology can be realized. The current situation is rather bleak in terms of the integration of UAS into agriculture. A private farmer simply cannot purchase a UAS and use it in his commercial practice. However, there is much hope for the future in terms of actually seeing rules and regulations being ratified and placed into action. Once these regulations are put in place, there needs to be a supply of adequate technology. Many companies are currently designing and constructing many different styles of UAS that will be acceptable for agricultural use. The next step in this process is determining the right type and style of UAS to be used for private agriculture.

CHAPTER IV

METHODS

4.1 Choosing an Unmanned Aircraft

The choice of sensor and sensing platform is critical to the success of any study using remote sensing as a primary tool. In this case, it is especially important because the platform will be completely controlled by the end user. With satellite remote sensing the end user is at the mercy of the platform specifications chosen many years prior by a team of engineers and managers. The flexibility of UAS is strongly suited for the variations that agricultural remote sensing requires. The size, shape, sensor, cost and many other important factors of the UAS are left to the discretion of the end user, the farmer. This is one of the many advantages of UAS remote sensing in agriculture when compared to satellite remote sensing.

The choice of unmanned aircraft is critical to the mission success. The selection of aircraft needs to be specific to the particular needs of each individual private farmer. Many factors must be assessed when deciding upon which unmanned aircraft to use for an agricultural study. The area of coverage, target of study, temporal resolution, spectral resolution, and many other factors will all need to be considered. Once these factors are established it will be easier to narrow the choice of unmanned aircraft. However, there are also many factors contributing to the differentiation of each unmanned aircraft. These factors include price, payload capabilities, altitude limitations, duration of flight, and many other factors. A thorough evaluation of all these requirements will be necessary.

There will be an obvious give-and-take throughout the process and eventually the right UAS with the right sensor will be chosen to gather the desired data.

The research conducted in this study was centered on the premise of a private farmer owning and operating his own unmanned aircraft. The requirements of the aircraft for this type of objective were obtained by talking with local farmers and hearing their needs and desires. The most important needs are that the UAS needs to be lightweight, small and portable, inexpensive, easy to use, and useful.

The University of North Dakota (UND) owns many UAS platforms including the military grade InSitu Scan Eagle, the AeroVironment Raven B, and the CropCam. Each of these aircrafts are quite different and the selection of the correct aircraft was critical to the outcome of the results of this study. The CropCam was chosen because it fulfilled four major requirements for the mission objectives where the other three aircraft could not. These three aircraft are similar in many respects, however, there are some major differences between the aircraft that make the CropCam the obvious choice. Table 1 lists the basic specifications of each aircraft side-by-side.

Table 1. Specifications of the CropCam, Scan Eagle and Raven B.

	CropCam	Scan Eagle	Raven B
Wing Span	8 ft	10.2 ft	4.5 ft
Length	4 ft	4.5 ft	3 ft
Empty Structure	6 lbs	28.8 lbs	Not available
Max Takeoff	8 lbs	44.0 lbs	4.2 lbs
Ceiling	2,200 ft	19,500 ft	500 ft
Endurance	25-50 minutes	24+ hours	60-90 minutes
Cruise Speed	60 km/h	90 km/h	45 km/h
Fuel	Lithium ion	Gasoline	Lithium ion
Launch Method	Hand-launch	Pneumatic catapult	Hand-launch
Recovery Method	Belly-landing	SkyHook wingtip	Deep-stall
Navigation	GPS	GPS	GPS

4.1.1 Lightweight, Small and Portable

The first of the three significant requirements for the use of UAS in a private agriculture is that it needs to be lightweight, small and portable. The days of a family working a small plot of land surrounding their quaint farm house are left in the past. Today, farmers are increasingly cultivating land throughout their particular region by renting and leasing land from other owners. UAS rules and regulations have yet to be finalized, however, they will most likely include a provision that small-UAS must remain within eyesight whenever they are in the air. With this requirement in mind, a farmer will need to be able to quickly move from one field to the next to ensure complete UAS coverage of all his cultivated land.

All of the unmanned aircraft at the University of North Dakota (UND) weigh under 50 pounds and are generally considered to be small UAS. However, there are significant differences in terms of the size, shape, weight, and portability of each aircraft. The Scan Eagle, for example, weights roughly 40 pounds at time of launch. Due to the weight of the aircraft and the lack of a landing gear, the Scan Eagle also requires a portable pneumatic catapult to launch it into the air at the speed required for sufficient lift (Figure 5). The Scan Eagle also requires a special SkyHook system which uses a hook on the edge of the wingtip to catch a rope hanging from a 30-to-50 foot pole (InSitu, 2012). Although the images and data the Scan Eagle collects are impressive, the additional infrastructure required for launch and recovery make the Scan Eagle less than ideal for the typical private farmer.

Figure 5: UND's Scan Eagle and Pneumatic Launcher.

The CropCam is the clear winner in this category when keeping the requirements of the end user, the farmer, in mind. The empty CropCam airframe weights about 6 pounds. Modifications may be made to the payload, increasing the total weight to seven or eight pounds. The total weight will never exceed eight pounds because the CropCam cannot carry a payload larger than one pound. The CropCam does not require an expensive launcher for takeoff or a special contraption for landing. The CropCam is hand launched and lands on its belly under the guide of either the pilot in command (PIC) or the ground control station (Figure 6).

Figure 6. The Hand Launching of the CropCam.

Another important feature of the CropCam that increases its portability is that it breaks down into many pieces. The eight foot wing can be pulled apart into three sections while the tail fin detaches leaving an empty fuselage. This makes the CropCam extremely easy to store. The CropCam does not come with a specific case in which to store it in. An off-the-shelf gun case was purchased and used for the storage of the airframe (Figure 7). Foam was cut to size and placed inside the case. Sections were cut out of the foam to fit the contours of the various pieces of the CropCam airframe. Storing the CropCam in a gun case makes it extremely easy to transport from one location to another. It can be put in the back of a truck or even in the backseat of a car. The case will be easy to store in a closet or shelf because it takes up very minimal room. Farmers typically have a large warehouse or workshop on their property so finding a place to store a small gun case should not be an issue.

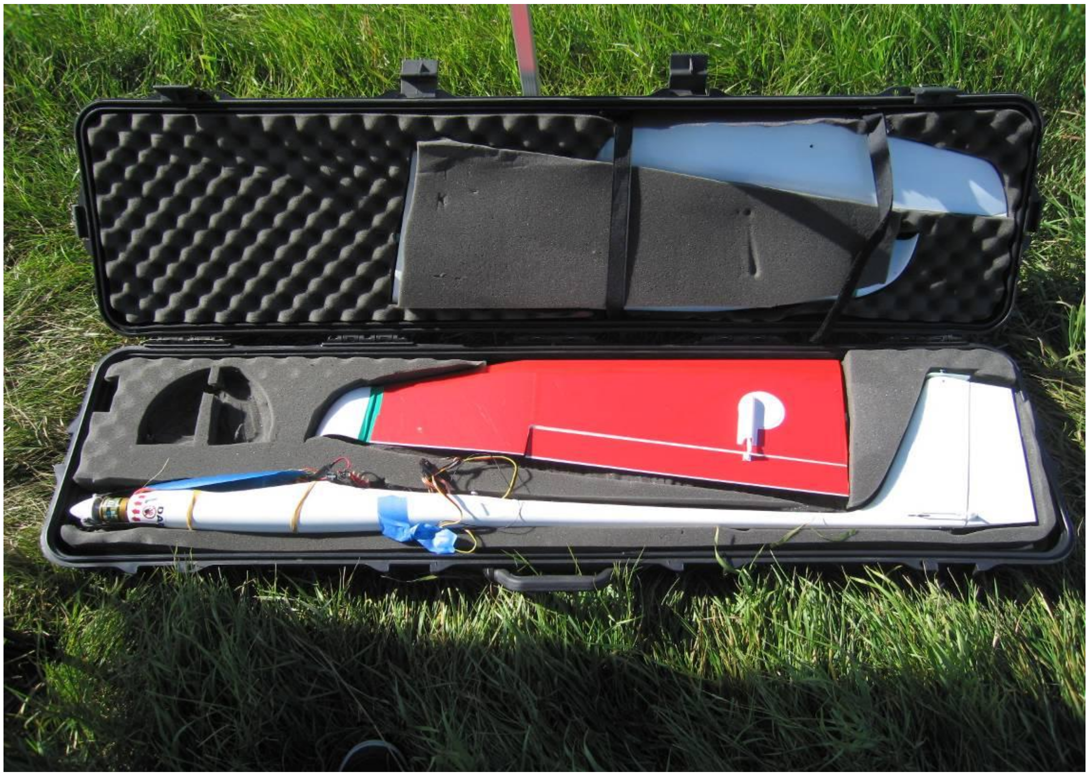


Figure 7. CropCam in Gun Case.

4.1.2 Inexpensive

The Scan Eagle, Raven B and the CropCam are relatively the same size and shape, however, they are quite different in cost. The Scan Eagle and Raven B were designed with military use in mind. The materials are more ruggedized and machined with a much higher quality and precision. The payloads on both aircraft are interchangeable and typically contain very expensive and highly specialized sensors.

The Scan Eagle, for example, was designed to provide real-time, direct situational awareness and force protection for the Air Force security forces expeditionary teams (U.S. Air Force, 2012). The official website for the United States Air Force lists the cost of the system at US$3.2 million. However, it should be noted that the Air Force undoubtedly uses a highly modified and advanced version of this system including armored cars, a specialized ground control station and highly trained personnel. The additional infrastructure and personnel would likely be unneeded for scientific or commercial purposes. Even with the cost reduction for civilian use, a multi-million dollar system is way out of reach for the typical private farmer.

The Raven B, an Aerovironment product, is much more similar to the CropCam than the Scan Eagle. The Raven B is about half the size of the CropCam, with a wing span of 4.5 feet. The aircraft itself only weighs 4.2 pounds and has an endurance of about 60-90 minutes (AeroVironment, 2012). The price of the Raven B and its accompanying system are not widely available, however, it is estimated that the cost of a single Raven B is about US$35,000 and the total system costs about US$250,000 (GlobalSecurity, 2012). This cost is significantly less than the Scan Eagle but still too high for the typical farmer.

The CropCam is currently listed at the sticker price of US$7,000. This price includes the airframe, autopilot, GPS, Pentax digital camera, and the preprogrammed GCS software (CropCam, 2011). This cost, however, is not for a military outfit or an institution of higher learning. The end goal is to put this technology in the hands of the farmer. So the real question revolves around the US$7,000 price tag and whether the average farmer would be willing to pay for the technology.

Farming in the United States has gone from being a single family operation to a big money enterprise. Considering that the average price for a combine or tractor is approximately US$250,000 or more, US$7,000 is a relatively small amount (John Deere, 2012). The real issue is whether UAS technology can help improve yields, lower chemical use, and save the farmer money. If this can be done then farmers will have a major incentive to acquire and incorporate this technology.

4.1.3 Easy to Use

One of the biggest risks of incorporating UAS technology into everyday farming practice is that it is a new technology. Farmers, along with the general public, are unfamiliar with the nuances of UAS technology, aviation lingo, and the many other facets of the industry that are not common knowledge. However, for the CropCam, this is one of its biggest selling points.

As discussed previously, the Scan Eagle requires a special pneumatic catapult, SkyHook recovery system, and ground control system just for normal operation; much too difficult for the average farmer. The Raven B, on the other hand, is cut from the same cloth as the CropCam in terms of ease of use. Both the Raven B and the CropCam are hand launched, flown autonomously with a laptop computer GCS, and are easy to recover. However, due to the high cost of the Raven B, the CropCam remains the obvious choice.

4.2 The CropCam

The CropCam is a small unmanned aircraft produced by the Canadian company MicroPilot. The CropCam is equipped with a Trimble GPS, miniature MicroPilot autopilot, and a Pentax digital camera. It is hand launched and can land under the control of the autopilot and GCS. According to MicroPilot (2012), the spatial resolution of the images taken with the Pentax digital camera at 2100 ft AGL are around 15 cm. Table 2 lists the specifications of the CropCam.

Table 2. CropCam Specifications.

Source: CropCam.

CropCam Specifications	
Length	4 feet
Wing Span	8 feet
Weight	6 pounds
Engine	Axi Brushless
Duration	20-35 minutes
Batteries	4 L-Polymer
Surfaces	Rudder, elevator and ailerons
Average Speed	60 km/h
Maximum Winds	30 km/h

The CropCam airframe is just one piece of a much larger system (Figure 8). The entire system is required to make the CropCam fully autonomous. Without the support system the CropCam would essentially be just another RC plane. The support system consists of the laptop GCS, data sender/receiver, RC controller, GPS unit, autopilot, pilot, and observer. All of these features work in tandem to make the CropCam autonomous.

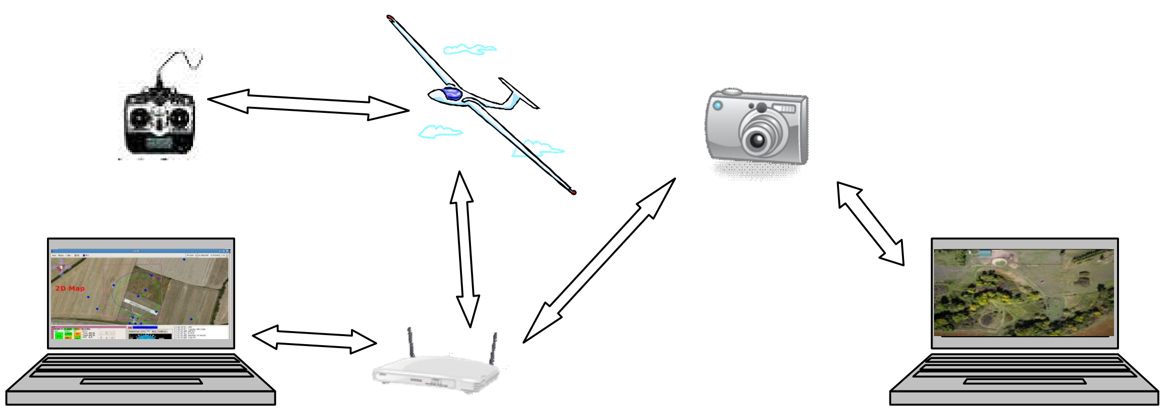


Figure 8. The CropCam Unmanned Aircraft System

The CropCam uses an onboard autopilot for navigation. Before any flight the user creates a flight plan on the Horizon GCS software that is included with the purchase of the airframe. This software was intentionally programmed to be user-friendly. The first step is to download a map of the area of interest from a program like Google Earth. After the image is loaded into the software, the flight path is created. The software comes preprogrammed with a wide variety of useful flight patterns. We choose to use a flight path called, 'survey' as our base flight plan. It is a basic pattern that has sequential lateral legs with both an away and return trip.

The flight path displays on the screen with pink lines representing the flight path and pink circles representing the waypoints (Figure 9). The waypoints may be adjusted with a drag-n-drop method anytime before or during the flight. This makes it easy for those who have minimal experience with RC flight controls.

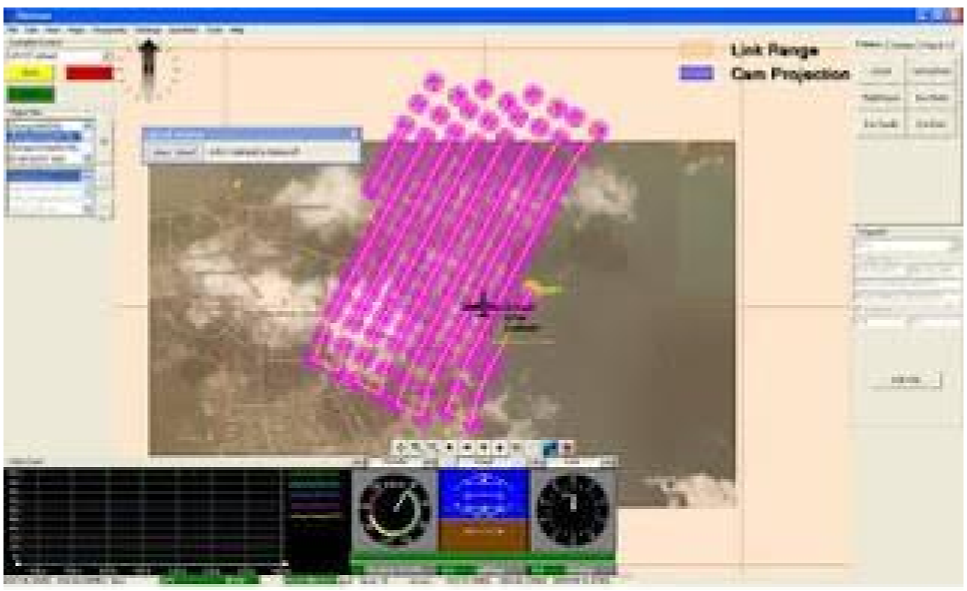


Figure 9. Screenshot of the Horizon GCS software.

Once the flight plan is finalized, it is loaded onto the CropCam and the plane can be launched. Once the CropCam achieves the predetermined altitude it begins following the way points. The flight path can even be modified during flight by dragging-n-dropping any of the waypoints. The usability of the Horizon GCS software makes the CropCam a particularly useful airframe for beginners.

4.3 Site Selection

Because of the FAA guidelines described in 08-01 and our desire to remain compliant with all officially issued rules and regulations, we restricted the activities for this study to designated areas approved by the FAA. Because of this major restriction and our desire to fly over actual farmers fields, we were required to submit CoAs for approval to receive clearance to fly over the desired cultivated land for this study.

We preferred to simulate a condition in which a farmer detects an issue in his field, we fly over his troubled area, capture images with the CropCam, and the farmer uses these gathered images for further analysis of the situation. Three local farmers were selected and agreed to participate in the project. These three farmers were selected because of differences in agricultural style and their willingness to participate in the study. One farmer is a highly mechanized precision farmer, another uses what can be considered the integrated approach to farming with precision methods and sustainable concepts, and the last is a strictly organic farmer. It was our hope that we would work closely with these farmers throughout the growing season. When they detected an anomaly in their fields that they wanted to investigate further, we would come to their fields, image the area with the CropCam, investigate what type of information the images provide, and how useful that information was.

The previously approved CoAs for the CropCam did not include the areas of these three farmers so CoAs were processed for two of the three farmers. The organic farmer lived within five miles of the Fargo, ND, airport and thus her farm was too close to major air traffic for the FAA to allow our flight operations. The other two CoAs were submitted in March 2011. They were not completely processed and approved by the

FAA until late October 2011, much too late for any significant study to be conducted using real conditions.

At the time of this study, UND had four previously approved and active CoAs for the CropCam. It was the desire of the study participants to continue with the study using one of these four CoAs. Of the four CoAs, one was deemed acceptable due to its close proximity to the school, the cultivation of corn at the site, and the land owner's approval for us to conduct our study over his property. This CoA is known as the Flying-S CoA (Figure 10 and 11).

Flying-S is an area just west of Larimore, ND. The area had been used previously for CropCam activity and pilot training. The site also was populated with a corn field, so it was deemed a suitable replacement for the absence of the participating farmers CoAs. Eleven flights were conducted in the Flying-S location between September 2010 and September 2011. These flights occurred during six flying days.

The Flying S CoA restricted our operations to, "Class G and E airspace at or below 1,200 feet Above Ground Level (AGL) in the Flying S operating area under the jurisdiction of Grand Forks Air Force Base (AFB) Radar Approach Control (RAPCON)". We did our very best to remain compliant with this advisory and were very successful in doing so. At no point throughout all of the six flying days did we stray from the CoA boundaries or altitude ceiling.

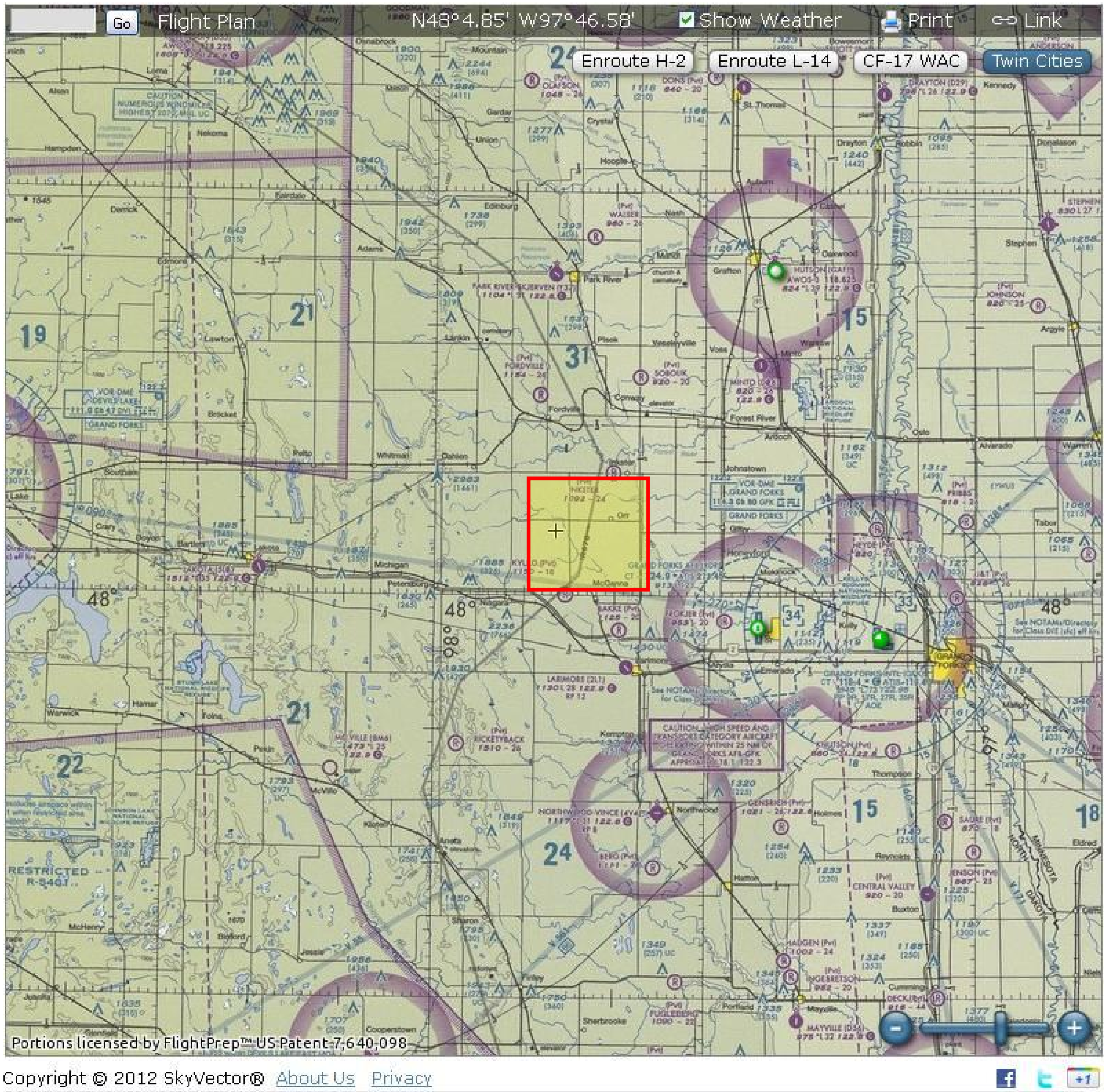


Figure 10: Small Scale View of the Flying-S CoA.

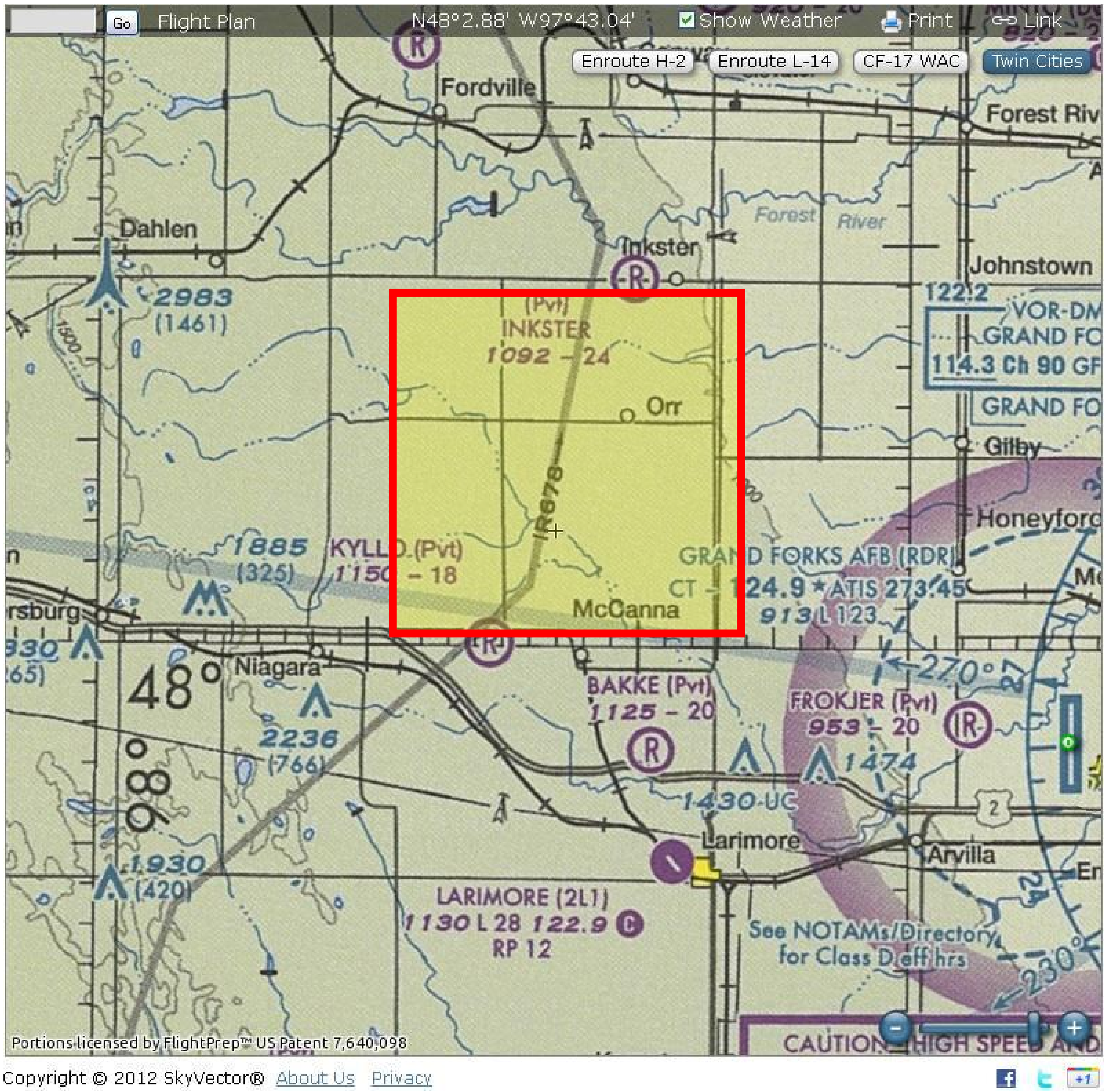


Figure 11: Large Scale View of the Flying-S CoA.

4.3.1 Applying for Certificates of Authorization for Farmer's Fields.

The first CoA that we applied for was for an area of airspace over a farmer's fields just to the southeast of Crookston, MN. UND has many experienced aviation experts, including many that are strong representatives of the many nuances in the CoA process. There are many factors the FAA looks for when reviewing and approving a CoA. The first and most important is that specified mission will be able to be conducted safely. This includes a thorough explanation of all contingency plans about lost link between the GCS and the UAS, accident procedures, mitigation strategies, and many other factors that represent the overall safety of the airspace.

The highly mechanized, precision farmer owns multiple fields to the southwest of Crookston, MN. The center point of his fields was obtained and was used to center the CoA boundaries. This Crookston CoA was specifically shaped to keep in accordance with the safety requirements and to minimize the potential for accident as much as realistically possible (Figure 12 and 13). The CoA is centered around the farmer's fields of study. The fields are located in the middle of two victor airways. Even though our operations would be conducted at an altitude below these airways, we carved the shape of our CoA to keep the boundaries at least a mile away from both airways. It was thought that this foresight would speed up the process of approval, however, due to an unforeseen FAA budget crisis, the shutting down of the UAS office for a couple of weeks, and the fact that the CoA approval process is still relatively new, we did not receive approval for this CoA until eight months later in October 2011.

The farmer who practices the standard methods of modern agriculture owns fields to the northwest of Grafton, ND. The center point of his fields was obtained and was used to center the CoA boundaries. A similar approach was given to the Grafton CoA in an effort to expedite the CoA process. However, carving out a realistic CoA for this farmer's fields was much more of a challenge. The fields are located adjacent to the I-29 interstate and a close proximity to the Grafton Airport. The first step in the process was to create a square of airspace centered above the farmer's fields. The section that crossed the highway was then removed and the boundary of the CoA was drawn back even further to create a buffer between it and the interstate. The southeastern corner was then removed to keep the CropCam a safe distance from the Grafton Airport.

The Grafton CoA was completed within the same week as the Crookston CoA and was approved the same day as the Crookston CoA. The airspace designated in the Grafton CoA is quite small and great care will need to be taken when operating within this area to make sure the aircraft doesn't stray outside of the CoA boundaries.

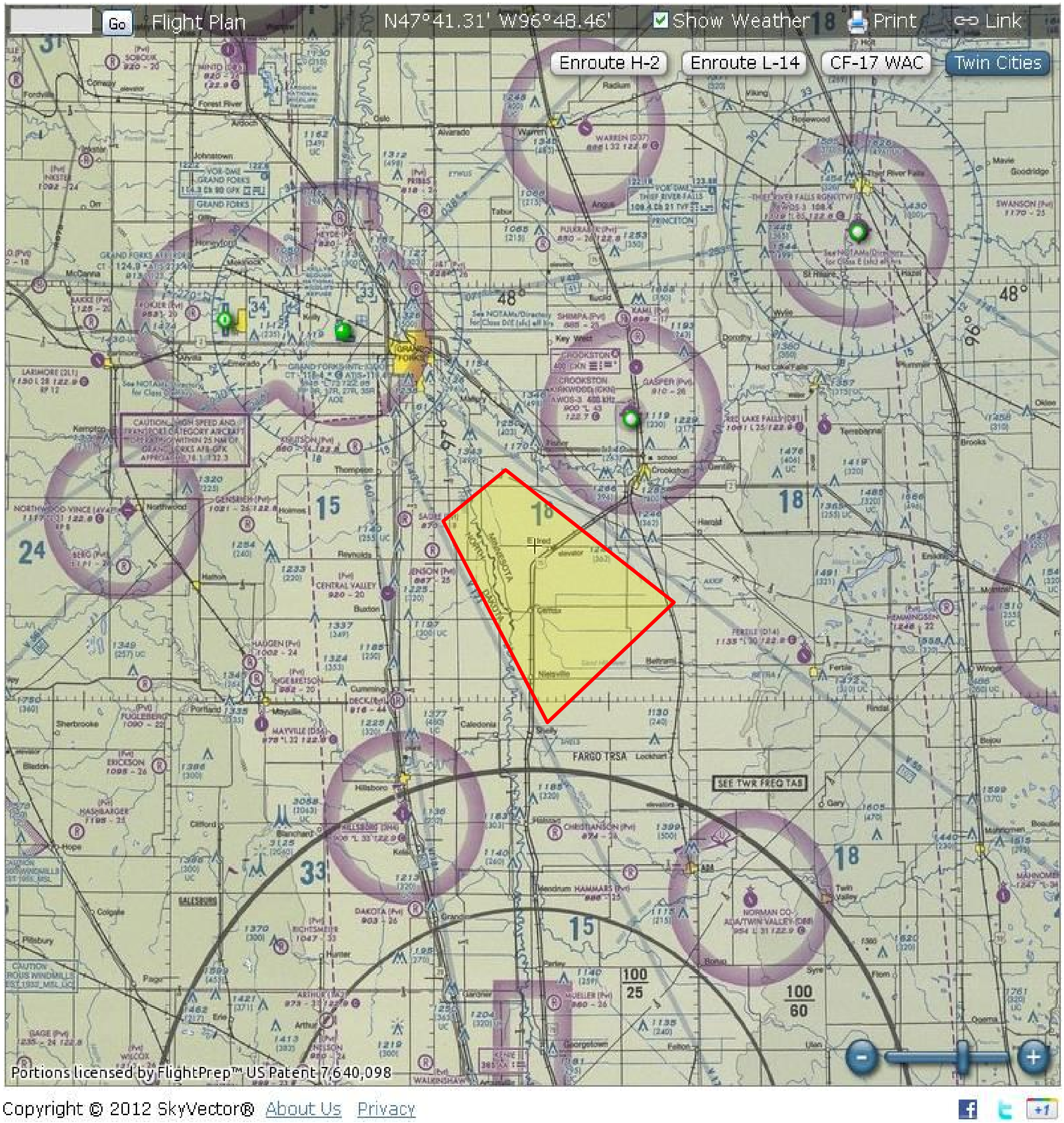


Figure 12: Small Scale View of the Crookston CoA.

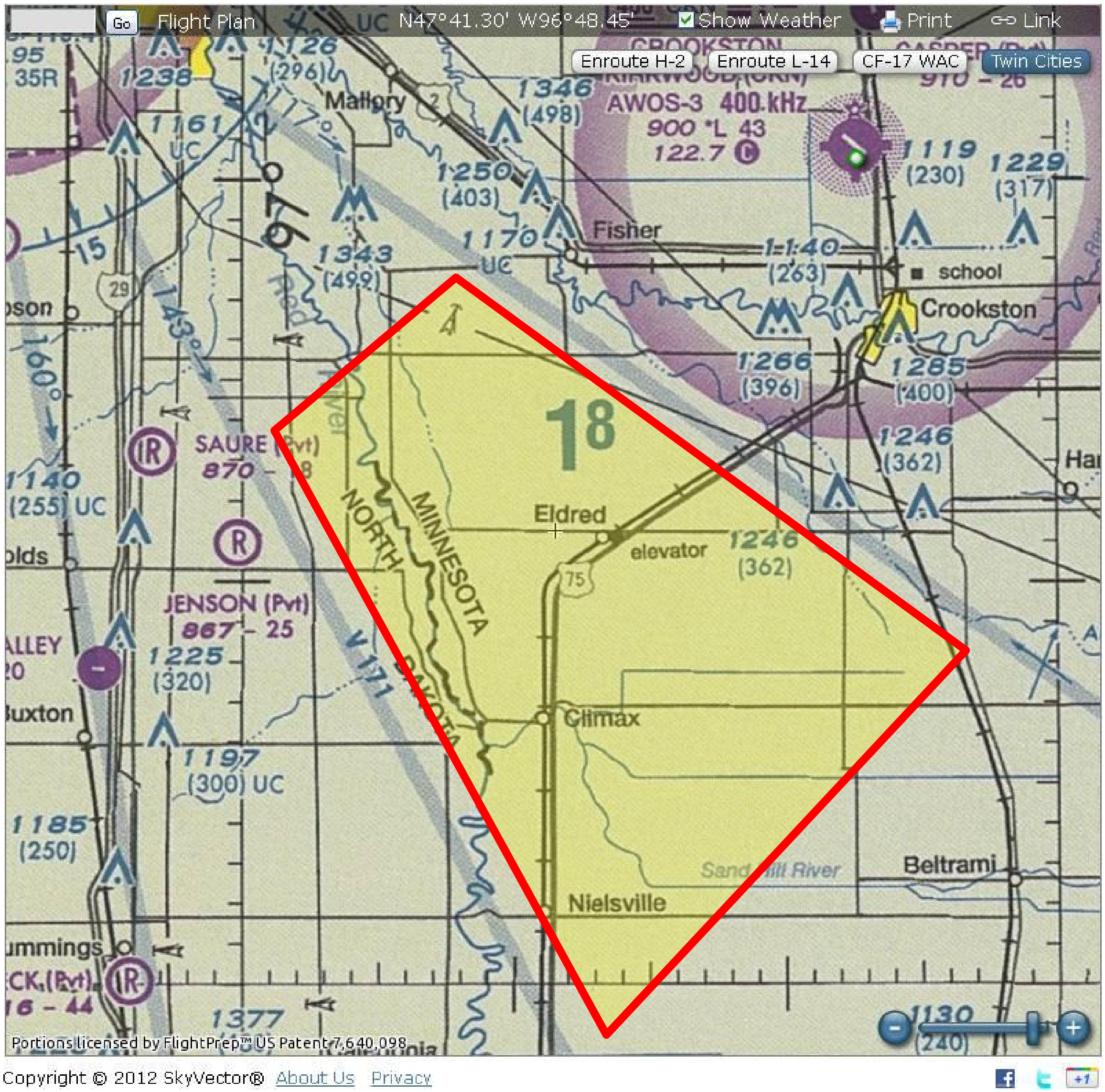


Figure 13: Large Scale View of the Crookston CoA.

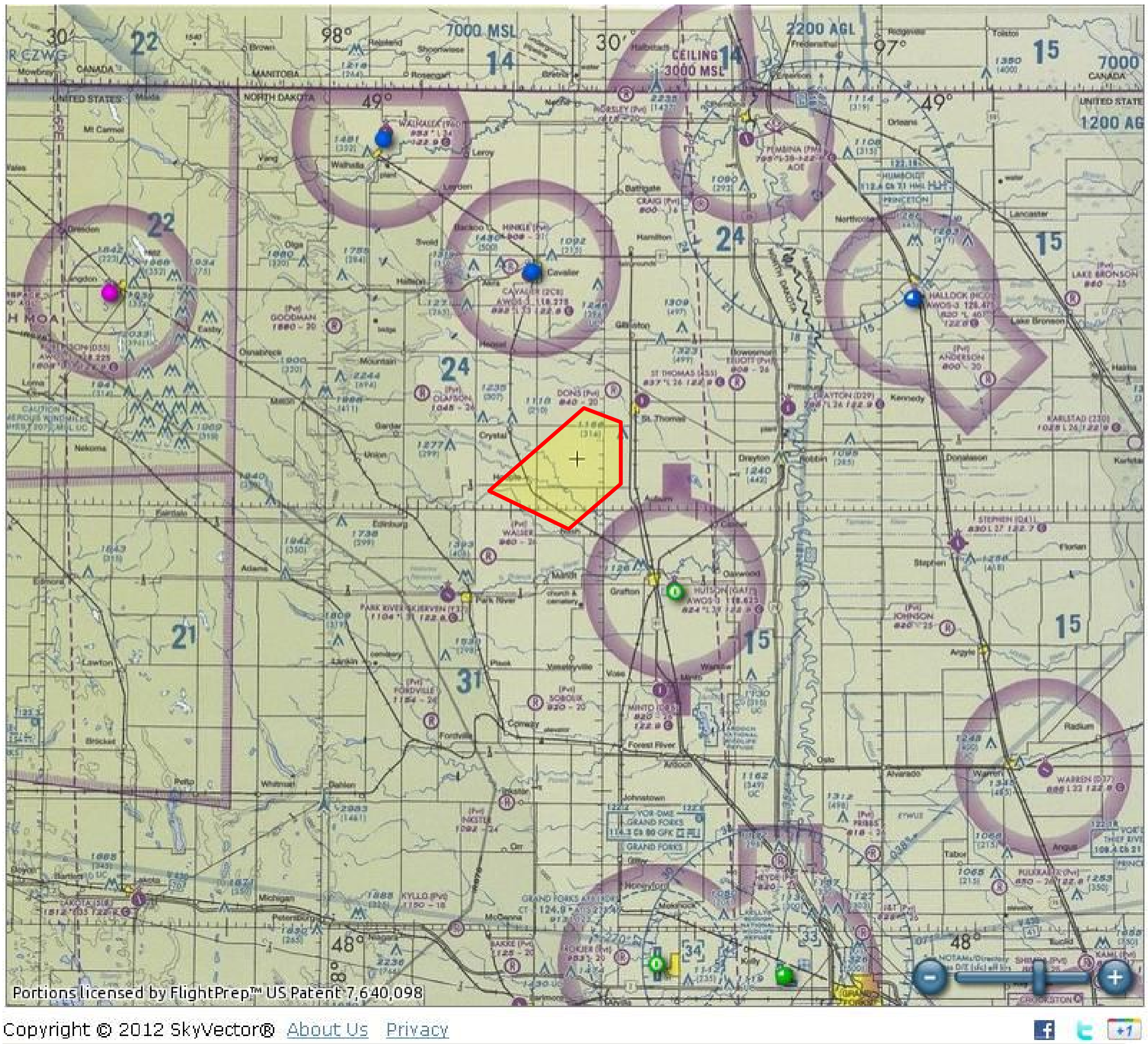


Figure 14: Small Scale View of the Grafton CoA.

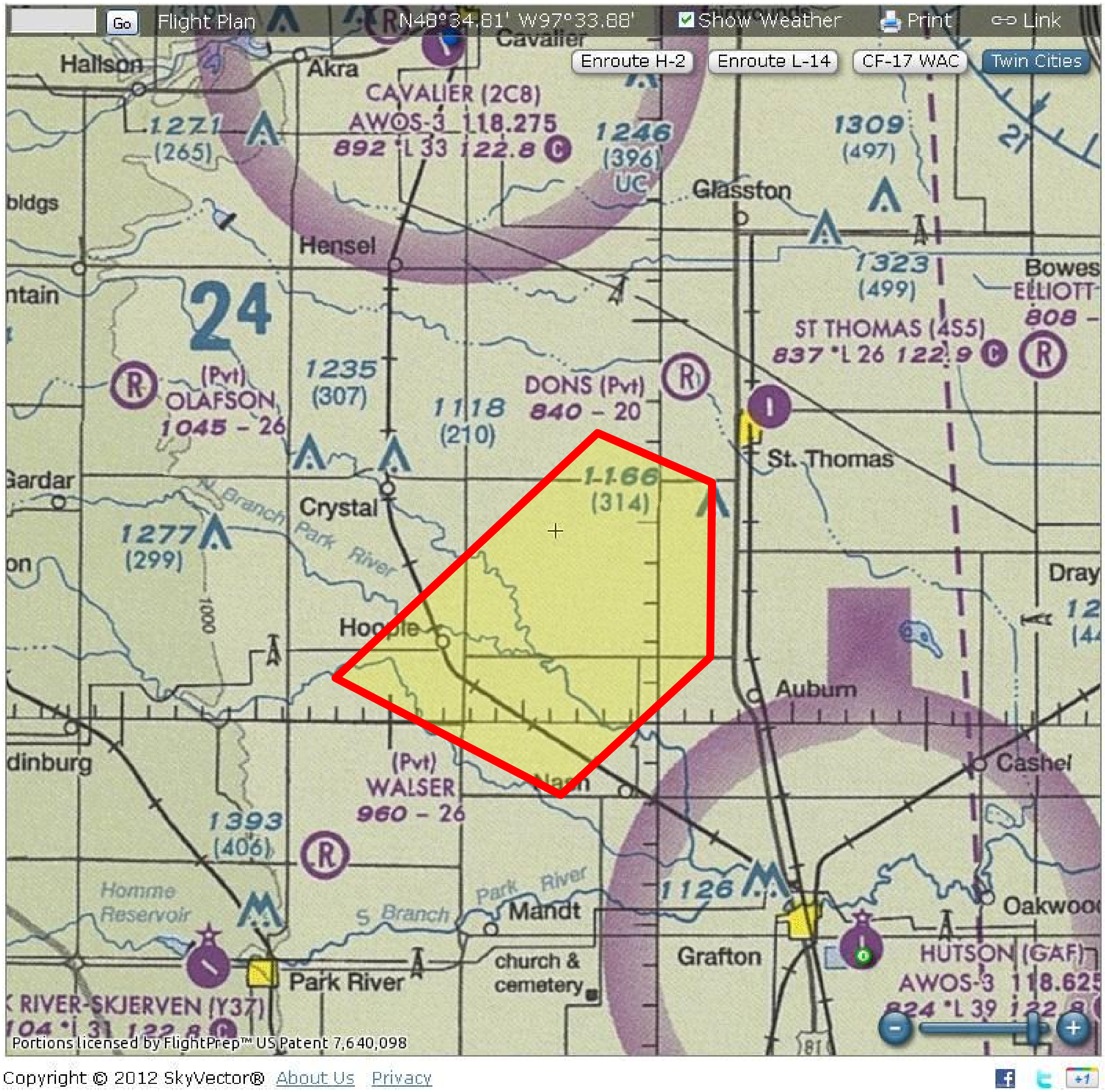


Figure 15: Large Scale View of the Grafton CoA.

4.4 Camera Selection

MicroPilot has chosen to include one Pentax Optio A40 with the purchase of the CropCam airframe. The Pentax Optio A40 is a point-n-shoot digital camera. It is a great example of the kind of off-the-shelf style digital camera that would likely provide the most benefit for farmers (Figure 16). Point-n-shoot digital cameras are quickly becoming an attractive alternative sensor for a CropCam style UAS because of product availability, user friendliness, compact size, and their easy image analysis capabilities (Ritchie *et al.*, 2008).

Figure 16. Pentax Optio A40 12 MP.

Another feature that is special with the Pentax Optio digital camera and that is beginning to be included on many new point-n-shoot digital cameras is anti-shake technology. This technology corrects camera shake when photographing still images by shifting the CCD horizontally and vertically in relation to the amount of shake that the high-accuracy gyro sensors detect (Pentax, 2007). This feature is important because of the light weight of the CropCam airframe. The light weight causes the CropCam to be very susceptible to minor changes in wind. These changes cause many alterations in pitch, roll and yaw of the aircraft during flight. The anti-shake technology may help mitigate some of these changes and keep the images from being to blurry for analysis.

There are, however, a few downsides to point-n-shoot digital cameras for airborne remote sensing. The biggest downside to point-n-shoot digital cameras is that they are typically customized for a non-tech-savvy end user. The controls of the camera are automated and many of these features cannot be changed by the user. Some of these automated features include shutter speed, aperture, white balance, and contrast. This makes it impossible on many cameras to change important features that are related to remote sensing. Many times there is also a lack of reference to the settings were used when the image was captured. Without this information there is only a minimum amount of post-processing and image analysis that can be conducted. This is something I will attempt to account for and improve when conducting my study.

Another issue is that point-n-shoot digital cameras typically record images in the standard JPEG file format. This file format is great for quickly viewing and storing many photos for recreational use. However, the limited and compressed nature of this file format means that some data is lost when the image is created and stored. The main feature of remote sensing is the post-processing, data manipulation and analysis of the images. The lack of changeable features in the JPEG file format makes it difficult to do a major scientific analysis with the images.

The positives of the Pentax Optio A40 for the CropCam system are that it is easy to use and fully integrated into the system. The GCS sends a signal to the CropCam which then triggers the camera to take a picture by way of an infrared remote trigger. If the camera is not equipped with this feature it will not work with the stock CropCam system. That is why it is important to make sure that any new camera purchased for use on the CropCam has this feature.

4.4.1 Creating a NIR Point-n-Shoot Digital Camera

Ritchie *et al.* (2008) revealed that consumer grade digital cameras can be used as a basic system to estimate visible and NIR reflectance. They concluded that as long as several practical aspects are considered when using the cameras that they can be successfully used for remote sensing research. The basic premise behind this is that most point-n-shoot digital cameras have the ability to shoot in the NIR region.

All point-n-shoot cameras have a basic design of a lens that directs light onto a charge-coupled device (CCD). The CDD captures the light and produces a digital image that can be seen on the screen on the back of the camera or uploaded onto a computer. The CCD of any point-n-shoot camera has the ability to capture electromagnetic energy from about 350 – 1100 nm (Hunt *et al.*, 2010). This means that any CCD is capable of capturing some UV and much NIR energy (Figure 17). This is very troublesome for producing images that will be viewed by the human eye. The UV and NIR energy will alter the color of the RGB image and will produce distorted images. To combat these unwanted wavelengths, manufactures of digital cameras put a filter directly in front of the CCD which blocks any UV and NIR energy from reaching the CCD and obscuring the color image. By removing the filter you allow the camera to capture images with the UV, RGB, and NIR parts of the EM spectrum.

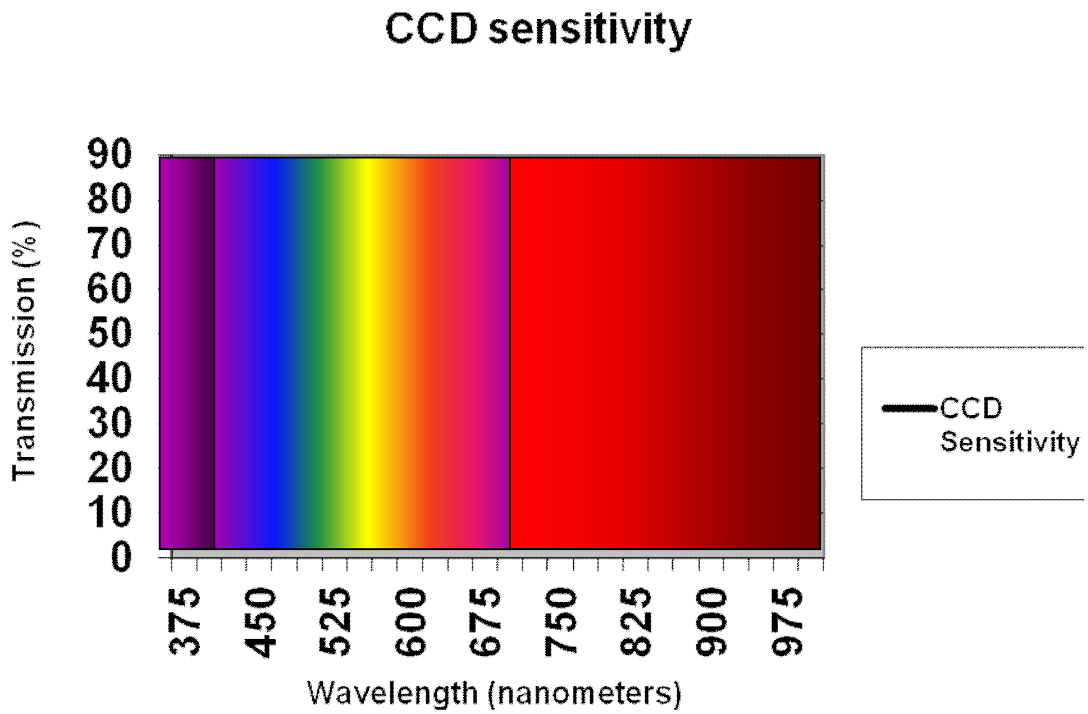


Figure 17. CCD Sensitivity with Accompanying EM Regions.

Placing a visible light filter in front of the CCD blocks all visible light and only allows the CCD to capture NIR light from 700 nm and up (Figure 18). This essentially turns the regular point-n-shoot camera into an infrared imager (Ritchie *et al.*, 2008). The process of replacing the filter requires the removal of the case, circuit boards, and LCD screen to allow access to the sensitive CCD. This is a tedious process and can completely destroy the camera if not done correctly. It was decided to purchase a camera that had the modification already completed instead of trying to complete the task in house.   The Canon S70 digital point-n-shoot camera was selected because it is infrared remote trigger capable and there is a company that provides this camera with the NIR modification.

Two cameras were purchased, one standard RGB and one the other the modified NIR version.

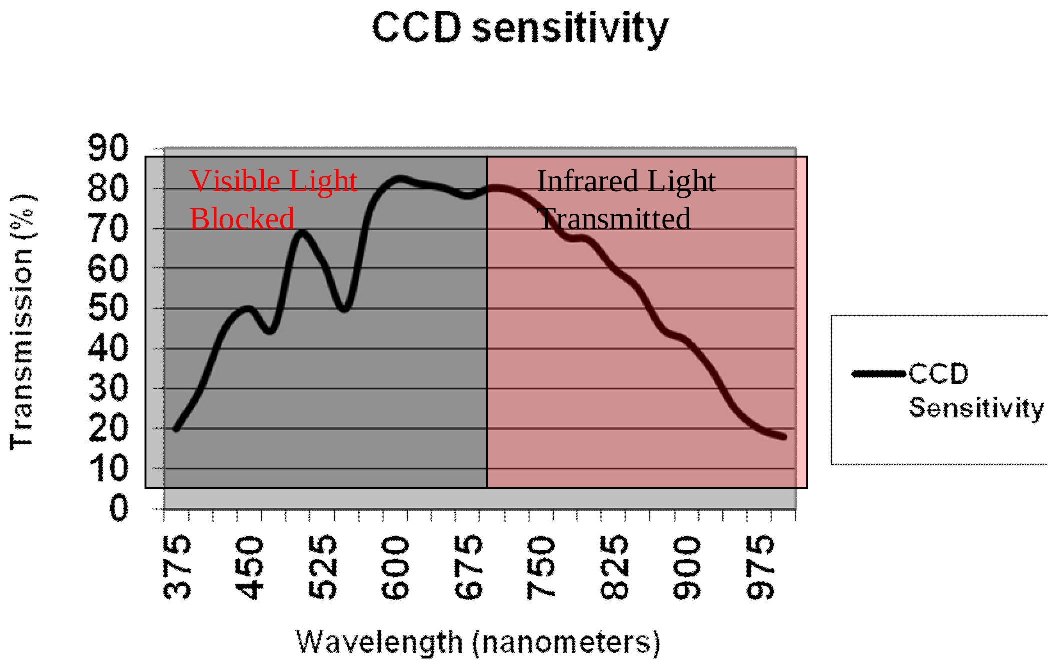


Figure 18. NIR Filter Blocking Visible Light and Allowing NIR Light to Pass to CCD.

Figure 19. Canon S70 7MP.

Ritchie *et al* (2008) has demonstrated that NDVI and other vegetation indexes can be accomplished using point-n-shoot digital cameras that use the Cyan-Yellow-Green-Magenta filter array. They determined that the blue channel is the most sensitive to infrared light and should be used for NDVI and other indexes. Ritchie *et al* (2008) also concluded that the blue channel correlated well with 800-900 nm but was relatively insensitive to 700-800nm. This makes it optimal for NDVI. It was determined that the Green band was sensitive to both the 700-800 nm range as well as the 800-900 nm range. This might be of interest because the 700-800 nm range is the region of rapidly increasing plant reflectance or the vegetation red shift.

Using the Bayer filter design, Hunt *et al.*, 2010, concluded that the red/NIR channel had the most spectral sensitivity to NIR. They found that the blue and green channels only had very small spectral sensitivity to about 725-800 nm. Using the black-dyed paper method described in Hunt *et al.* (2010) it can be determined if the particular digital camera has blue and green channels sensitive to IR light.

4.5 Selection of Acquisition Time for Data and Images

One of the goals of this project was to compare satellite, manned aircraft, and unmanned aircraft images all collected on the same days. A calendar was created to display the days that Landsat 5 would image the Flying-S CoA area. It was the hope of this study that all three platforms; satellite, manned, and UAS, would be able to image the corn field in the Flying-S CoA on the same days. However, there were many outside factors that prevented this from happening on any occasion. First and foremost, Landsat 5 has a pre-determined 16-day temporal resolution. That means that each time it flies over it arrives on a different day of the week. All participants of this study were either full-time employees of UND or full-time students/part-time employees. It was not feasible on any occasion to fly the CropCam on the same day as the Landsat 5 pass. Due to these outside factors it was determined that if the flights could occur within 5 days of the Landsat 5 pass that a comparison would still be reasonable. Three out of the five CropCam flying days in 2011 occurred within five days, proceeding or following, the Landsat 5 pass. Most of the CropCam flights occurred on the Saturday or Sunday following or preceding the Landsat 5 pass.

4.5.1 Satellite Image Data

The Flying-S CoA area is covered by path 30 and row 27 of the Landsat 5 TM. Path and row are the worldwide index system of location Landsat satellite images for any location in the world. Six Landsat 5 images were collected between June 2011 and September 2011 (Table 3). However, only the image on the 30th of July was found suitable for image analysis. The June 28th image had cloud cover but the area of interest was visible with minor cloud shadows (Figure 20). The Flying-S area of interest in the image is outlined with a yellow box. Although the area of the Flying-S CoA is visible, the large amounts of clouds and cloud shadows would make image analysis difficult. The other four images were seventy-five percent or more cloud cover and the Flying-S CoA area was completely covered by clouds.

Table 3. List of Satellite Images for this Study.

Year	Day	Landsat	Sensor	Source
2011	12-June	5	TM	USGS
2011	28-June	5	TM	USGS
2011	30-July	5	TM	USGS
2011	15-Aug	5	TM	USGS
2011	31-Aug	5	TM	USGS
2011	16-Sept	5	TM	USGS

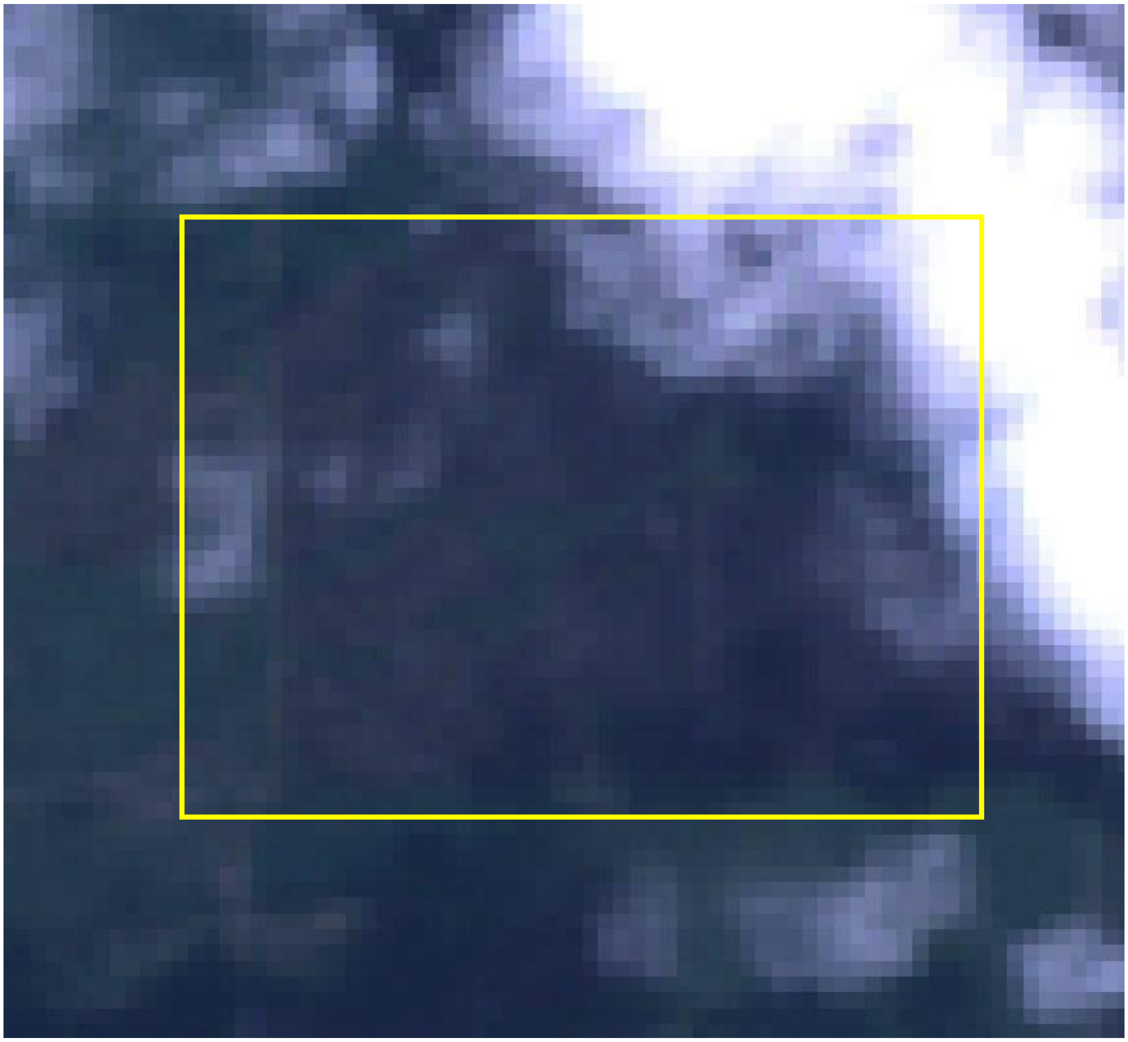


Figure 20. Landsat 5 image, 28-June-2011.

The Landsat images were downloaded from the U.S. Geological Survey's (USGS) website, using the GLOVIS geospatial tool. The image from the 30th of July was geometrically corrected using a USGS topographic map of the area also obtained through the GLOVIS geospatial tool. No other satellite images were processed due to the complete cloud cover in each image. All digital image processing was performed with the ERDAS Imagine 2011 (Leica Geosystems, Atlanta, GA) geospatial software.

The image from the 30th of July was of excellent quality with very little atmospheric noise. The EMR signals collected by satellites in the solar spectrum are usually modified by scattering and absorption by gases and aerosols while traveling through the atmosphere from the Earth surface to the sensor. This modification of EMR signals can be fixed through a process known as atmospheric correction. Accurate atmospheric corrections require simultaneous in situ spectral measurements of ground objects or target. No atmospheric correction was applied on the images acquired for this study because no simultaneous *in situ* spectral measurements of ground target data was taken at the time of image acquisitions.

4.5.2 AEROCam data

The Airborne Environmental Research Observational Camera (AEROCam) is a remote sensing device that is flown on a manned aircraft. The service, run by UND, provides imagery for farmers, ranchers, and researchers in the upper Midwest. Imagery flights are available upon request through the AEROCam website (UMAC, 2012). However, it should be noted that there is no guarantee that all of the requested dates will be accomplished (Table 4). The AEROCam can capture images in two different sets of 3-band combinations. The first is a red, green, blue (RGB) band combination and the second is a NIR, red, green (CIR) band combination. The CIR band combination was chosen for this study so that vegetation indexes could be completed with the images. The AEROCam images have a spatial resolution of about 2 meters and are similar to UAS imagery in that the images are not georeferenced.

Table 4. List of Manned Aircraft Images for this Study

Year	Day	Aircraft	Sensor	Accomplished
2011	12-June	AEROCam	NIR	No
2011	14-July	AEROCam	NIR	Yes
2011	15-Aug	AEROCam	NIR	Yes

To meet the objective of comparing a satellite, manned aircraft, and UAS images the only AEROCam image that was useful was the image taken on 15-Aug as it is the closest to the 30th of July Landsat image. Ground control points (GCP) on the non-corrected AEROCam image and corresponding GCP on the base image (Landsat image from 30th of July) were identified and the image-to-image geometric correction function in ERDAS Image 11.0 was applied. However, because of the low spatial resolution of the Landsat 5 image and the small area covered in the AEROCam image, only ten control points could accurately be identified. The average root mean square (RMS) error was 0.928. It is generally considered that an RMS error of less than 1 pixel is acceptable (Jensen, 1996). No atmospheric correction was applied to the image due to the lack of *in situ* corresponding measurements during image acquisition.

4.5.3 CropCam Data

CropCam images were captured on 6-flying days between September 2010 and September 2011. Four of the six flying days included multiple flights. Images were collected at four different altitudes; 400 ft, 600 ft, 800 ft, and 1,000 ft (Table 5). Two sensors were used; the Pentax Optio A40 and the Canon S70. Using the Pentax Optio, images were captures in RGB in the JPEG file format. Using the Canon S70, images were captures in both RGB and NIR and in the JPEG and RAW file formats.

.

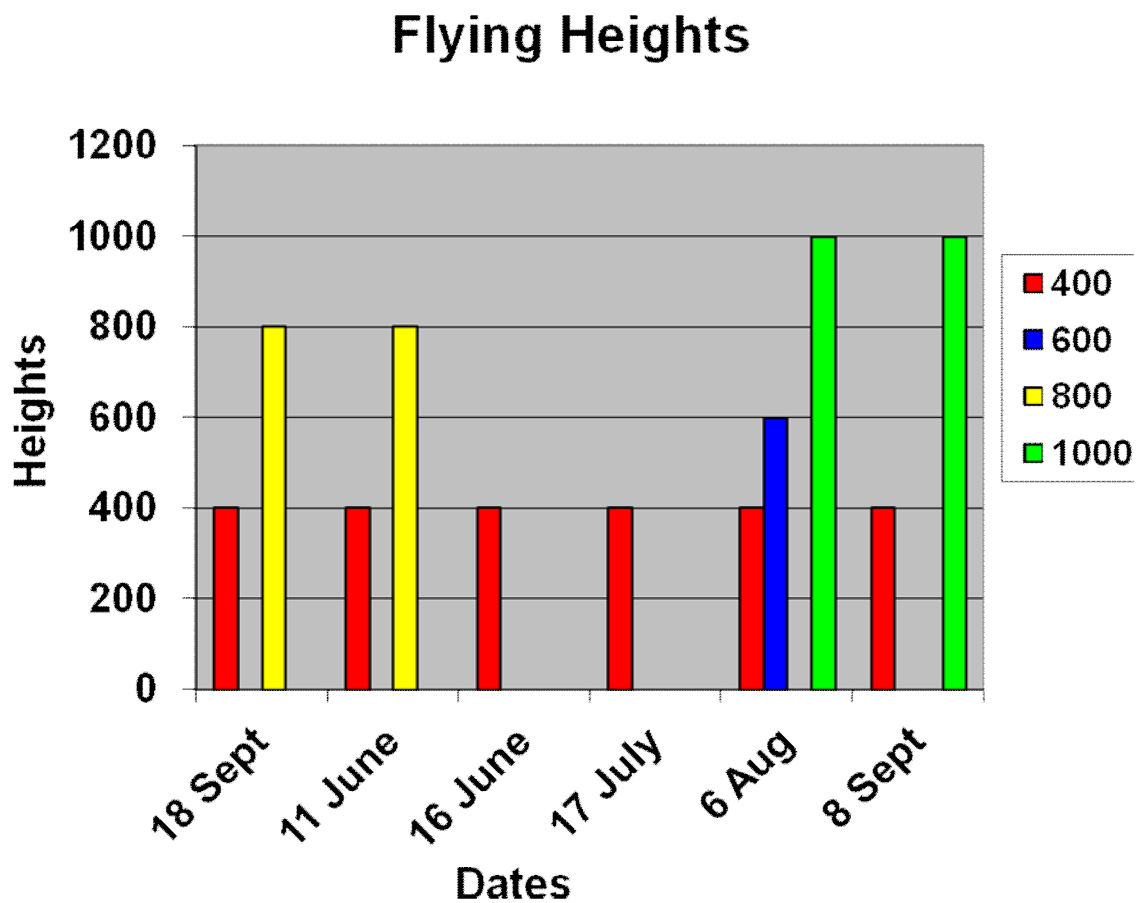


Figure 21. Flying Heights for CropCam Flying Days

After each flight, the images were immediately downloaded onto a computer for storage. Following the flying day, the images were analyzed to determine if an image mosaic was possible. If it was decided that it was possible, the images were mosaicked using a low-cost image stitching program called PTGui (PTGui.com). This software looks for similar pixel groups in corresponding images and stitches them together based upon these corresponding control points. On many occasions, the computer could not determine control points and they had to be inserted manually.

The image mosaic was processed using Adobe Photoshop to remove the black background that is applied in the PTGui software. The image mosaic was then geometrically corrected using the image-to-image geometric function in ERDAS Imagine 2011. Due to low spatial resolution of the Landsat 5 image and the small area covered by the image mosaic, about ten GCPs were identified in each image mosaic that was geometrically corrected. None of the image mosaics were atmospherically corrected due to the lack of *in situ* measurements at the time of image acquisition.

Table 5. List of CropCam Images for this Study.

Year	Day	Flight #	Altitude	Sensor	Type	Data File
2010	18-Sept	1	400 ft AGL	Pentax	RGB	JPEG
2010	18-Sept	2	800 ft AGL	Pentax	RGB	JPEG
2011	11-June	1	400 ft AGL	Canon	RGB	CRAW
				Canon	NIR	CRAW
2011	11-June	2	800 ft AGL	Canon	RGB	JPEG
2011	16-June	1	400 ft AGL	Canon	RGB	JPEG
				Pentax	RGB	JPEG
2011	17-July	1	400 ft AGL	Canon	RGB	JPEG
				Canon	NIR	JPEG
2011	06-Aug	1	400 ft AGL	Canon	RGB	JPEG
				Canon	NIR	JPEG
2011	06-Aug	1	600 ft AGL	Canon	RGB	JPEG
				Canon	NIR	JPEG
2011	06-Aug	1	1000 ft AGL	Canon	RGB	JPEG
				Canon	NIR	JPEG

CHAPTER V

ANALYSIS AND RESULTS

5.1 Review of Flying Days, Post-Processing, and Results

5.1.1 Flying Day 1 – 18 September 2010

The purpose of the first flying day was to familiarize myself with the CropCam aircraft, the Horizon GCS software, gather color images at 400ft and 800ft AGL with the Pentax Optio point-n-shoot digital camera, better understand the capabilities and limitations of the CropCam system for agricultural use, and to identify possible solutions for these limitations that could be implemented during the next growing season. Due to the late flying time, 18-Sept-2010, the crops at the Flying-S location had already been harvested. However, the main purposes of the flight could be conducted with or without crops present. The temperatures were very cold, hovering around freezing. The wind speed varied between 7 and 20 mph throughout the day. Images were captured on two flights using the Pentax Optio point-n-shoot digital camera.

For this first series of test flights, the GCS was placed in the middle of the flight path to ensure that the hay bales near the GCS were imaged. The hay bales were used as a size reference to help estimate the area coverage of each image at different heights. The survey pattern for the first flight contained seven total legs. The CropCam was launched by hand and when it reached 400ft AGL began executing the waypoints.

There were some issues with flight 1. The CropCam only relayed an Easting GPS coordinate to the GCS and did not relay a Northing GPS coordinate. The

CropCam was obviously receiving a Northing GPS coordinate because it was flying the flight path correctly. It was determined that the situation was still safe and that the flight could continue. The CropCam finished its flight path and landed safely under the control of the PIC.

During the second flight the CropCam was programmed to run the same survey flight path as flight 1 but at 800ft AGL. After the CropCam was launched it began to hover in the air about 20-feet off the ground with no forward movement. The PIC took manual control of the aircraft and increased the airspeed. This fixed the problem and he gave control back to the autopilot. However, the CropCam began to lose forward momentum again and was on the verge of a stall. The PIC took control of the CropCam again and after a couple of exchanges between the autopilot and the PIC he decided to land the CropCam safely and investigate the problem. No images were captured during this flight.

It was determined that the engine controller was not running correctly. A controller from another CropCam was placed into active CropCam. However, after the controller was installed the active CropCam would no longer function. The controllers were returned to their original aircrafts and it was decided that the previous CropCam would be flown again without the Northing GPS points.

During the third flight the CropCam was programmed to run the same flight path as flight two at 800 ft AGL. The winds by that time had increased to a steady 12 mph with gusts up to 15 mph. Due to the increased wind speed the CropCam experience significant changes in altitude during the flight. The airspeed was increased to 42 knots to try and dissipate the movement. This had virtually no effect. The airspeed was lowered back to 33 knots in order to conserve battery life so the entire flight could be completed. Images were captured in JPEG format with the Pentax Optio camera.

After the flights the images were downloaded to a computer for storage and image analysis. The images at 400 ft AGL had such a small footprint that it was almost impossible to determine the location of each image. There was no image overlap in any of the images. Without the GPS information from the CropCam I was only able to identify about four images and their locations.

The images at 800 ft AGL had a much larger footprint. On at least two runs, there was enough forward overlap to create an image mosaic of the leg. Due to the larger footprint of area in each image, I was able to manually locate almost all of the images. There were enough distinguishing features in each of the images to be able to identify their location. However, there were a few images that contained only bare ground and their location was not detectable.

Using the hay bales as a reference, it was determined that the area covered in each image at 400 ft AGL using the Pentax Optio digital camera was about 1.6 acres. Using this same method, it was determined that the area covered in each image at 800 ft AGL was about 6.7 acres.

5.1.2 Flying Day 2 – 11 June 2011

The purpose of the second flying day was to test the MP Vision, which is a beefed up version of the CropCam that can carry more weight. Since it is virtually identical to the original CropCam, the term CropCam will still be used to reference this aircraft. The purpose of the first flight of the day was to test the new camera pods with ballast weights to make sure the CropCam could carry the weight of two cameras. During the flight the minimum airspeed would be determined and adjusted to compensate for the increased speeds needed for the heavier aircraft. The final flights were to be used to test the new Canon S70 digital point-n-shoot cameras that were purchased using money that I received from the North Dakota View Scholarship. These cameras have the ability to capture both RGB and NIR images. The cameras were tested to check the dual capture of the cameras and check the use of the RAW file format.

The conditions for flight one were clear skies with winds at 5 mph, gust up to 7 mph. This flight was designed to test the overall safety and performance of the aircraft with a ballast weight to simulate the additional weight of the dual camera system. Ten ounces were carried in each of the camera pods to simulate the weight of the new cameras. The CropCam was launched into the air and immediately began to climb with the assistance of the new engine speed controller and autopilot in the MP Vision version of the CropCam. The path that was chosen was a simple figure-8 at 600ft, with a cruse speed of 30 knots. We chose this path because it kept the CropCam close to the GCS in case of a problem.

The aircraft climbed to 600ft and began cruising at 25 knots. Shortly afterwards, the CropCam tip-stalled and entered a spin during the first turn of the figure-8 pattern at 600 ft AGL. The PIC took control of the aircraft, recovered from the spin, and landed the CropCam safely. Some of the issues that were identified were that the additional weight draws additional power from the batteries. It was determined that this is not a catastrophic problem, however, the battery levels will need to be constantly monitored during the flight to avoid a power loss. It was also determined that the 30 knot average airspeed was not fast enough to keep the CropCam in flight with the additional weight, especially during turns. The minimum airspeed was adjusted to 40 knots.

The second flight had roughly the same weather conditions as the first flight. The flight path for this flight was a repeat of the first flight except with the increased minimum airspeeds. The CropCam was launched, climbed to 600ft, completed three figure-8s and landed safely. No images were captured during this flight because the cameras were not installed, only the ballast weights for testing. The CropCam was deemed safe to test fly with the cameras installed and taking pictures on the third flight (Figure 22).

By the time of the third flight, the wind had almost died, with only occasional gusts up to 5 mph. The CropCam was launched and safely climbed to 800 ft AGL. It flew the standard survey pattern with five legs forward and five legs back. Images were captured with both cameras during the entire flight. Upon landing the left wingtip caught some tall grass which spun the plane. The starboard camera pod took the brunt of the landing and was shattered (Figure 23). Both cameras survived the landing. It was determined that the camera pods needed to be built out of stronger material since they take the brunt of the landing due to their large size.

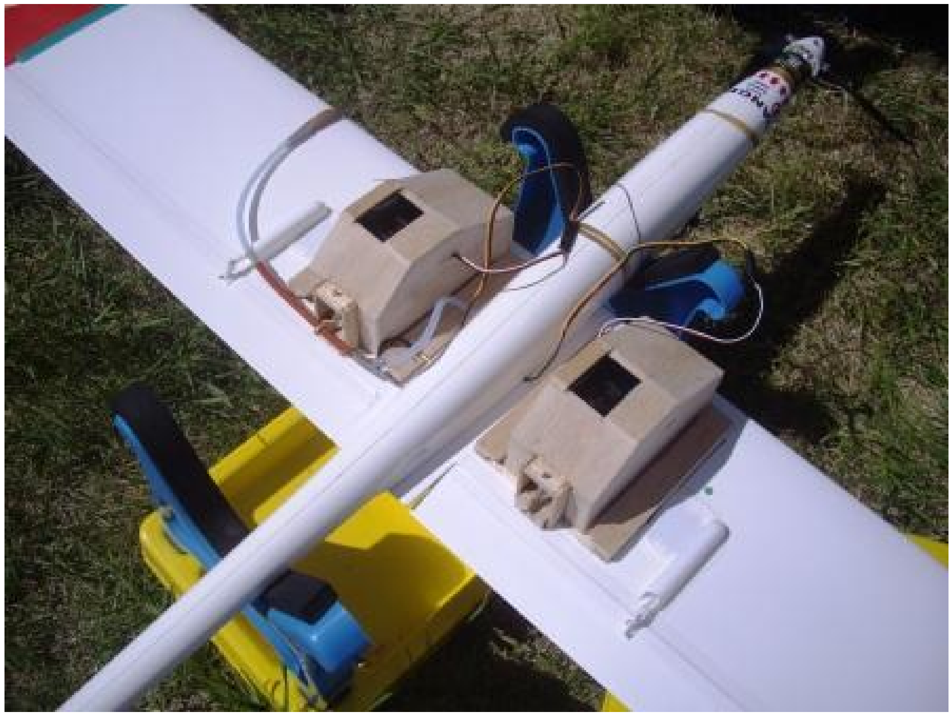


Figure 22. Camera Pods for the Canon S70.

Figure 23. Broken Camera Pod with Camera Still Attached to the Side of the Pod.

During the third flight significant thermal activity was identified as the CropCam would suddenly gain altitude. The thermal activity would rapidly push the CropCam from 800 ft to 900 ft AGL. The autopilot would try to correct the altitude by setting the throttle to zero. Many times the CropCam would glide with zero throttle for 10 seconds or more before it would regain the 800 ft desired altitude. It was noted that the thermal activity could pose a problem if flying close to the ceiling of the CoA. To stay within the CoA limits we decided we need to leave a ceiling buffer for future missions. Since our CoA ceiling was at set 1,200 ft AGL, we elected to not fly any higher than 1,000 ft AGL to stay within our CoA ceiling.

Both the RGB and NIR Canon S70 point-n-shoot digital cameras were installed for the third flight. The images were captured throughout the flight and were stored in the RAW file format. Later image analysis revealed that because of the additional data processing time that is required for the RAW file format most of the images had no overlap. It was noted that future missions capturing images in the RAW file format will need an altered survey flight path that drastically increases the forward and side overlap.

The conditions for the fourth and final flight of the day were about the same as the third flight. The CropCam only carried one camera because of the damage sustained during the previous flight. The one camera captured RGB images and stored them in the JPEG file format. The CropCam was launched, climbed to 800 ft AGL, and flew the same five leg survey pattern. It flew 800 ft AGL on the first legs (away legs) and 400 ft on the second legs (return legs). This was the only time during our studies that we let the CropCam auto land. We selected the ‘land@home” feature in the Horizon GCS software. The CropCam auto landed about 20 feet from the launch point. We also tested the functionality of the ‘circle right’, ‘circle left’, ‘circuit right’, ‘circuit left’, and ‘figure-8’ features on the GCS software. Each command was successful and the CropCam was extremely responsive to each command.

The post-processing of the images was completed the week following the flying day. The images from the third flight were capture in the RAW data format. This is a non-standard format for point-n-shoot digital cameras. A special photo-software was required to view the images. They were converted to JPEG file format for easier viewing. It is very unlikely that this type of file format would be ideal for private farmers. The special file format requires special software and conversion takes an extra step. Images were captured in this format to test advanced remote sensing techniques on images captured with a small UAS.

The JPEG images from the fourth flight were downloaded to a computer and examined. The most of the images were found to have sufficient forward and moderate side overlap. The images were mosaiced using a low-cost image stitching software available for download and purchase on the internet. During the flight it was noticed that the CropCam would severely overshoot the turn-around and begin the next leg hundreds of feet to the north of where it should start. This issue is can clearly be seen in the image mosaic. Figure 24 displays three light blue dotted lines which represent the legs of the flight the way they should have been flown. The first actual leg is represented by the red dashed line. The red line demonstrates the significant drift that can occur to small UAS during flights when there are high winds. When the CropCam turned around and transitioned from the red leg to the orange leg it severely overshot the first two waypoints of the orange leg. It still collected images while it was correcting itself, however, the result is that there is a large area of land that was not imaged. When the CropCam began the turn-around to transition from the orange leg to the yellow leg, the wind had died down and the CropCam did not overshoot the first waypoint of the yellow leg by as a large a margin.

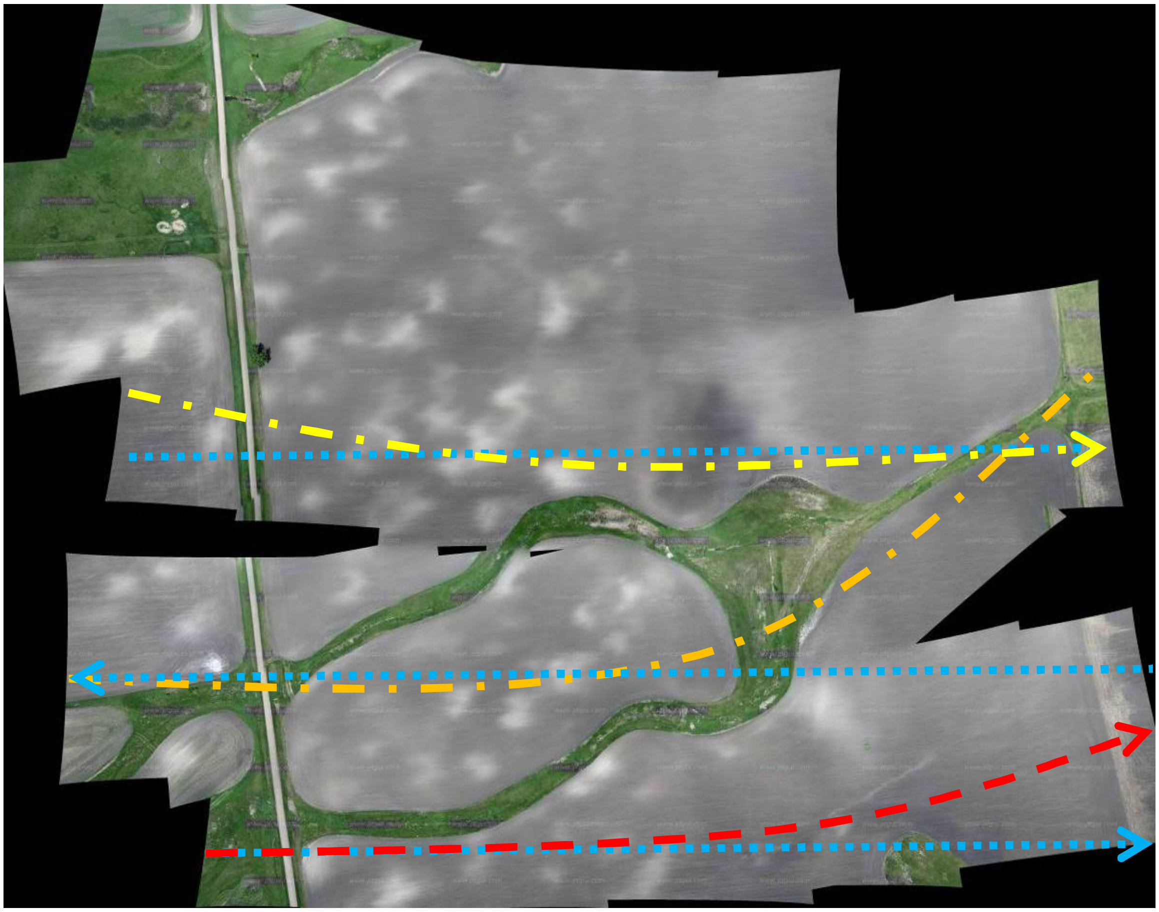


Figure 24. Flight 4 Image Mosaic with Planned and Actual Flight Paths.

As a result of this flying day the standard survey flight plan was adjusted to make the turnarounds much larger to correct for the overshooting of the first waypoints. The legs were also pushed together to help created more side-to-side overlap as a buffer to combat against drift.

5.1.3 Flying Day 3 – 16 June 2011

The purpose of the third day of flying was to use the Pentax Optio point-n-shoot digital camera and the Canon S-70 point-n-shoot digital camera to determine which one produces the best looking images and gives the widest angle view at different heights. This flying day was different than the rest because it was a tag-a-long mission with another study being conducted which uses the CropCam and a radar tracking system. Image collection was not the primary objective but a secondary objective.

The radar tracking study uses a system that is housed in a large fifth wheel trailer. The trailer requires the use of a generator and a support staff of around five-to-six people. The trailer was towed to the site, however, the soil was very muddy. The team did not think it was safe, due to the heavy weight of the trailer, to go down the dirt road to corn field. Instead, they decided to set up on the side of the road and image the field next to the corn field. The images captured on this day were not of the corn field at the Flying-S location and cannot be use for comparison with the Landsat 5 or AEROCam images.

The weather was very nice with virtually no wind throughout the entire duration of the day. However, the bottom of the cloud canopy was really low. For unmanned aircraft, it is safe to stay at least 500-feet below the clouds. We determined that 400-feet was the highest we could safely fly to comply with the regulations. Before the flight, we created a modified version of the survey flight path. The legs were moved closer together and a cover pass on both ends of the legs was created. We learned for the second flying day that a cover pass is needed because the CropCam tends to overshoot its turnarounds and misses the beginning of each leg.

The new flight path worked very well at 400 ft AGL. We were able to get almost complete coverage of a quarter section with the exception of a few small holes between a few images. The major theme that was displayed throughout the day that is the more equipment and the more complex the equipment is, the higher the likelihood of problems arising. Due the an issue with the generator and the radar tracking software there was about a two hour delay before we actually began flying the CropCam. Due to this delay, we were only able to conduct one flight. This is an important lesson when discussing the integration of UAS technology in agriculture. The fact that the CropCam system is so easy to use makes it very attractive for farmers.

The images collected with the Pentax Option digital camera were downloaded onto a computer. The images did not have enough overlap to complete an image mosaic. The Canon S70 images were also downloaded onto a computer. These images contained sufficient overlap to complete an image mosaic. The images were loaded into a low-cost image mosaicing software and mosaiced (Figure 25). Due to the absence of wind on this day the CropCam was able to hit almost every waypoint the way it was supposed to. The CropCam was not able to finish its entire flight due to a drain in the batteries from the extra weight of the two camera system. However, the CropCam was able to complete the eastern north/south cover pass. That is why the image mosaic contains more images to the north and south on the right (east) side of the main block of images than on the left (west) side.

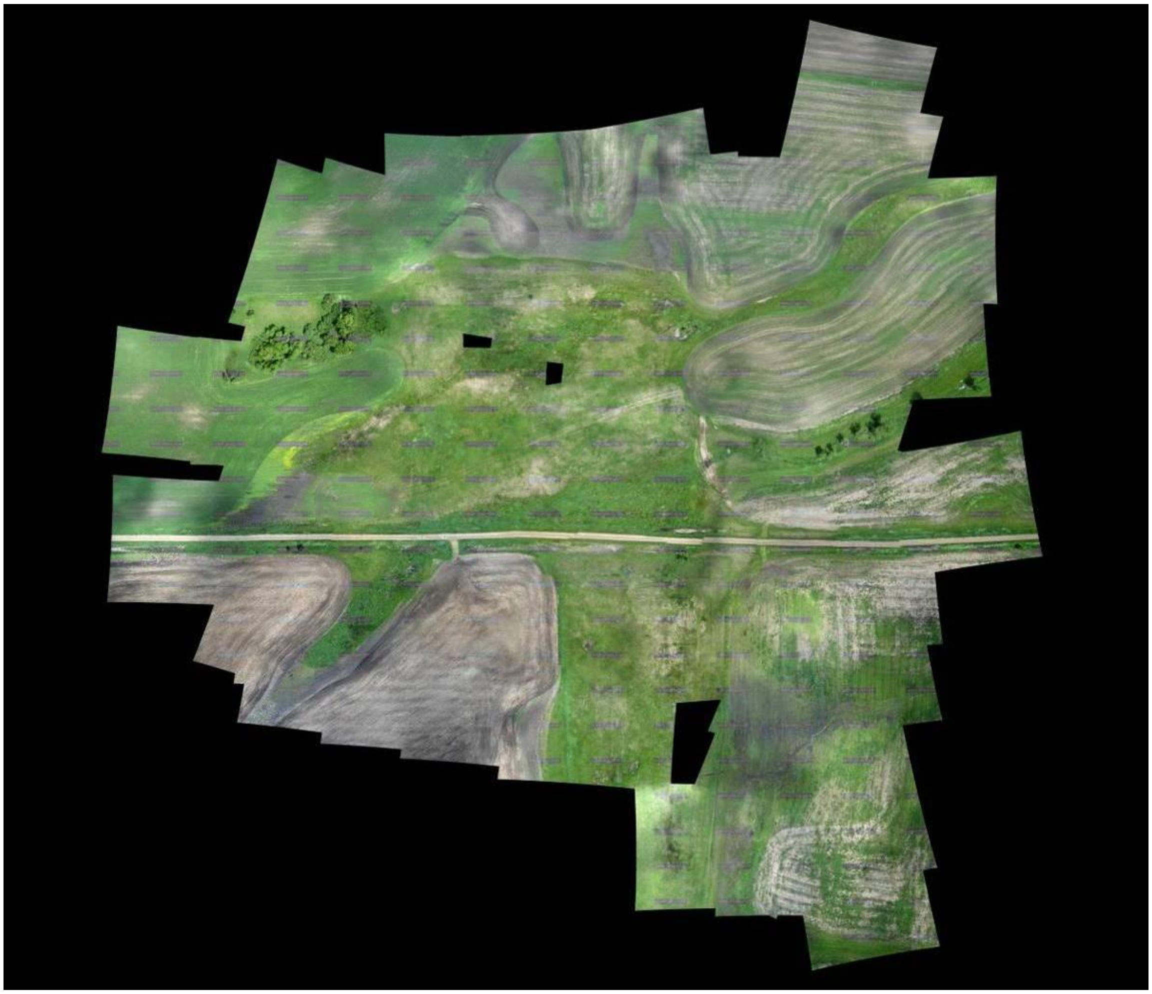


Figure 25. Flight 1 Image Mosaic.

5.1.4 Flying Day 4 – 17 July 2011

The main purpose of the fourth day of flying was to gather RGB and NIR images using the Canon S70 point-n-shoot digital cameras. All the flights of the day were going to be conducted at 400 ft AGL to try to continually modify and correct the survey flight path to obtain complete coverage. The images for this flying day were collected in the standard JPEG file format because this is most likely what format farmers will use to gather images when they use UAS in their private practice.

The first flight was conducted safely and images were collected with both cameras. However, the weather conditions for the day were very poor. The wind averaged about 10 mph with gusts up to 15 mph. Due to the high wind speed many images were blurry and the CropCam overshot all of the turns by a wide margin. The CropCam also experienced significant drift during each leg of the flight path. Many of the images are not aligned with the flight path because of the severe ‘crabbing’ that occurred while the CropCam tried to correct its position during flight.

The CropCam was prepped for a second flight, however, the weather conditions worsened the longer we were in the field. We checked the future weather conditions with a mobile phone and learned that a tornado-class storm was approaching our location from the northwest. We decided that it was not safe to stay in the field any longer and we packed up the equipment and left.

The images from the day were downloaded onto a computer and examined. Due to the extremely high wind speed, virtually all of the images contained no forward overlap or side overlap. An image mosaic could not be completed.

5.1.5 Flying Day 5 – 6 August 2011

The purpose of the fifth flying day was to capture images at 400 ft AGL, 600 ft AGL, and 1,000 ft AGL with the Canon S70 point-n-shoot cameras. The conditions for the first flight were partly cloudy with gusts up to 3 mph. The CropCam was launched and began its flight. Shortly after launch a manned aerial applicator was spotted and was heading directly in our airspace. It was obvious that this plane was going to go right through the middle of our flight path. The PIC took control of the CropCam and lowered its altitude to about 100 ft and directed it to the opposite direction of the manned aircraft. When the aerial applicator passed, the CropCam resumed the flight path. However, because of the interference of the aerial applicator, there was not enough battery to complete the north/south cover passes. After the flight the images were downloaded to a computer for later analysis and storage.

The purpose of the second flight was to conduct the same flight pattern with the same camera configuration at 1,000 ft AGL. The CropCam was launched and completed the flight without any problems. The CropCam was not able to complete the north/south cover passes due to battery drain. However, at 1,000 ft AGL the cover passes are not necessary because of the large footprint of the images at that altitude. It was also noted that the batteries were getting old and only held a charge for about a 20-minutes flight.

The purpose of the third flight was similar to the second flight, use same flight pattern with the same camera configuration at 600 ft AGL. The CropCam was launched and completed the flight without any problems. The CropCam again was not able to complete the north/south cover pass due to battery drain.

The images from the second and third flights were downloaded onto a computer for analysis and storage. The images from the 1,000 ft AGL flight in both the RGB and NIR contained sufficient forward and side overlap that the low-cost image stitching software was able to mosaic all of the images without manually-entered control points (Figure 26 and 27). It was also noted that at 1,000 ft there is no need for a return set of legs because the outgoing set of legs has sufficient overlap. With this discovery, it was realized that it might be possible to image an entire half section. The survey flight path was again modified to be tested on the sixth flying day. It was also noted that there is sufficient forward and side overlap at 1,000 ft AGL that even on a windy day there will probably be enough overlap for mosaicing.

The images from both the 400 ft AGL and the 600 ft AGL flights were examined for the possibility of image mosaicing. Both altitudes contained sufficient forward overlap but without the cover passes there were gaps at the beginning and end of each leg of the flight paths. It was noted that new batteries need to be purchased so that the cover passes could be completed for complete coverage at both altitudes.

Figure 26. Flight 2, 1,000 ft AGL.

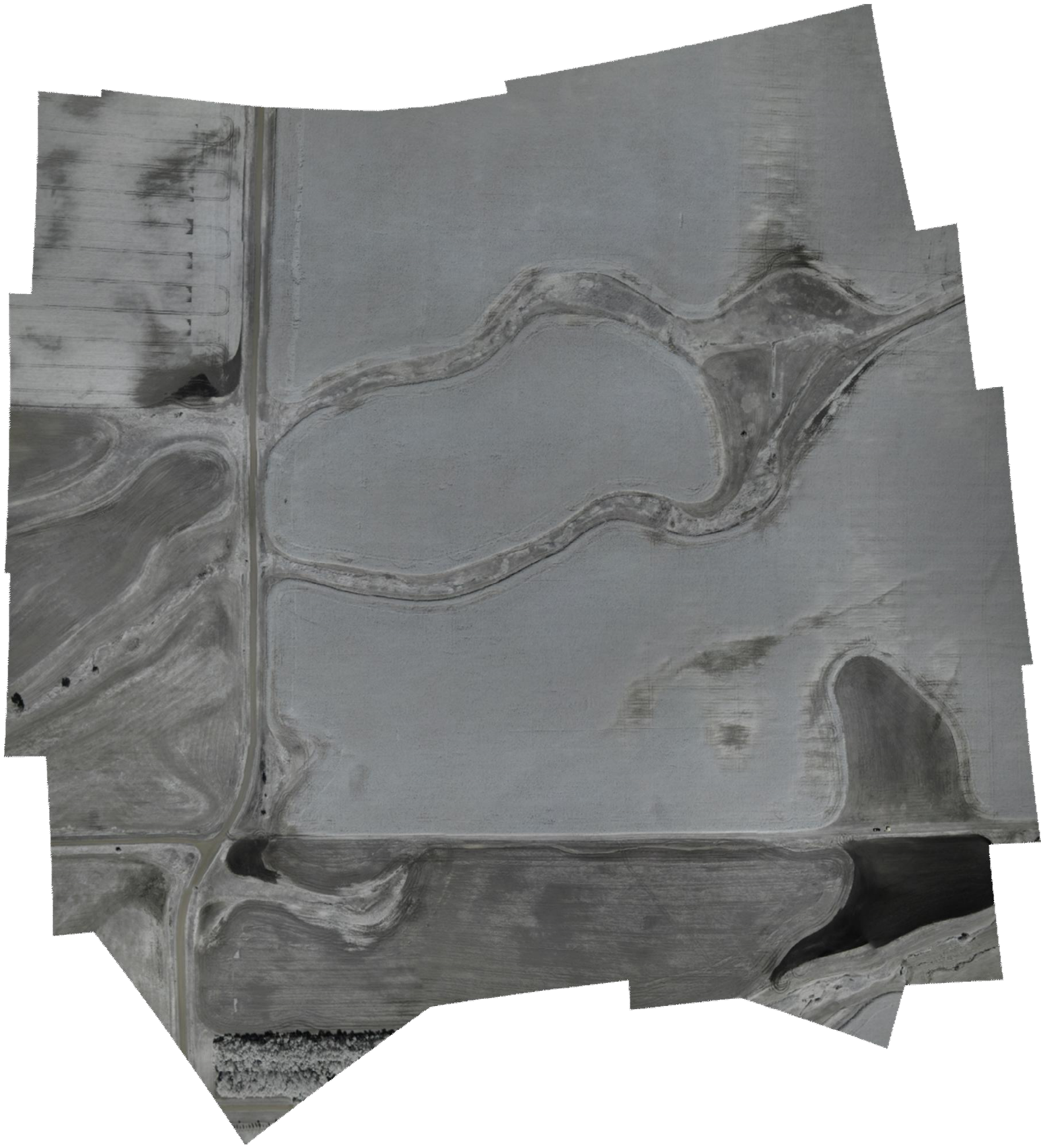


Figure 27. Flight 2, 1,000 ft AGL, NIR.

5.1.6. Flying Day 6 – 8 September 2011

The purpose of the sixth flying day was to test the modified survey flight path and to capture images to create an image mosaic for an entire half section. The CropCam was launched and completed the new survey pattern at 1,000 ft AGL. The extended distances of the new flight path made the CropCam very hard to see when it was at its furthest points. It was noted that when flying this flight path in the future a very close eye will need to be trained on the CropCam to make sure it is still functioning correctly and to stay compliant with the rules in the Flying-S CoA and regulations of 08-01. After the flight the images were downloaded onto a computer for storage and analysis.

The images were analyzed and found to contain sufficient forward and side overlap for image mosaic. The images were loaded into an easy-to-use, low-cost image stitching software. The software was able to stitch the images together with only minimal user input (Figure 28). The image mosaic contained no holes and there were no issues with the beginning or ends of the legs containing gaps. The results of this final flight are impressive and will be very useful for farmers. Farmers often plant crops in segments of half sections. Having the ability to image an entire half section in one flight will be a major benefit.

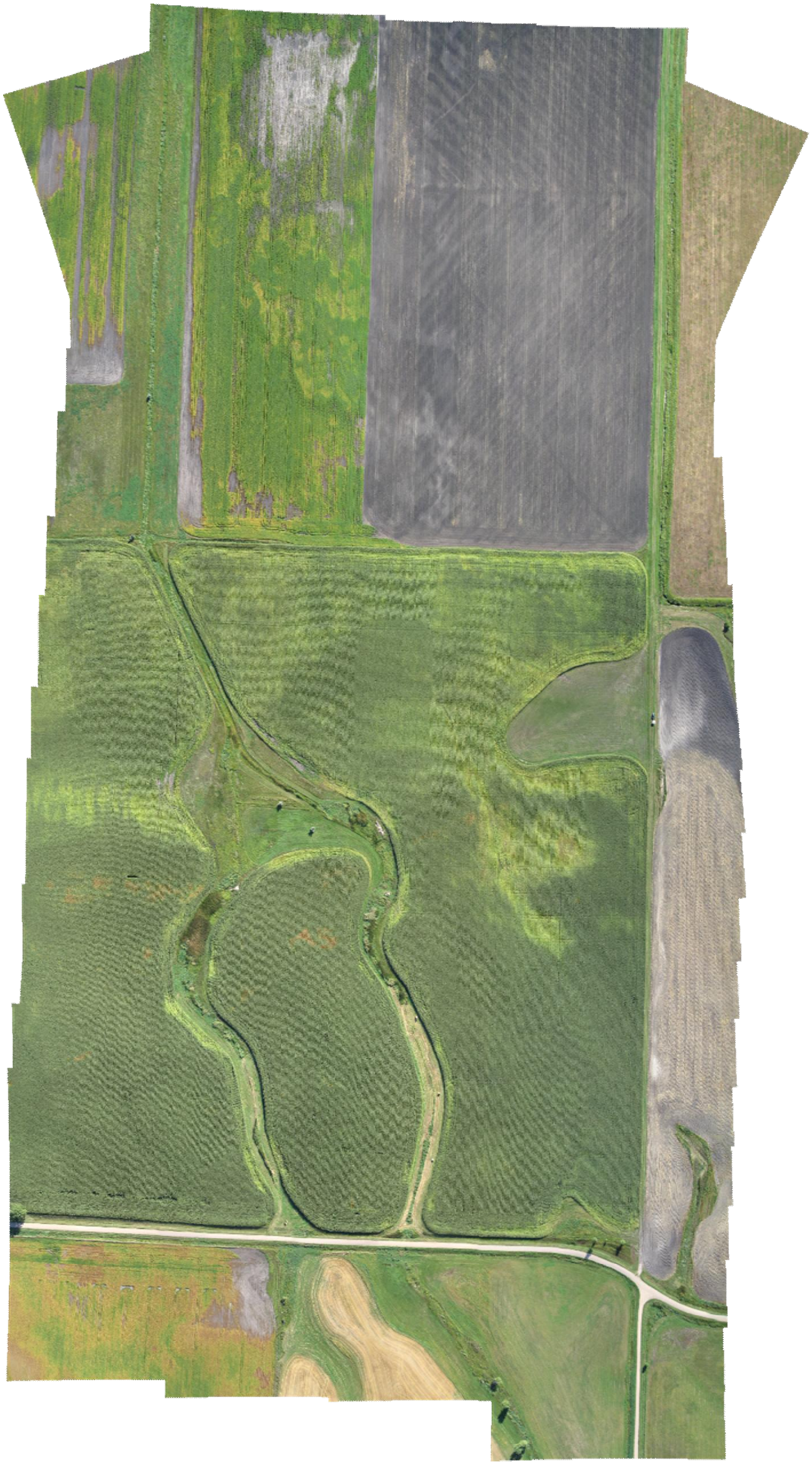


Figure 28. Flight 1, 1,000 ft AGL.

CHAPTER VI

CONCLUSIONS

6.1 Choosing the Correct Flying Height for Future Missions

The CropCam is advertised to have a maximum altitude of 2,100 ft AGL (CropCam, 2012). Due to the restriction of the Flying-S CoA we had a maximum ceiling of 1,200 ft. However, it should also be noted that 08-01 states, “Visual observer duties require the ability to maintain visual contact with the UA at all times while scanning the immediate environment for potential conflicting traffic. At no time will the visual observer permit the UA to operate outside their line-of-sight. This ensures that any required maneuvering information can be reliably provided to the PIC. The visual limitation will specify both a lateral and vertical distance and shall be regarded as a maximum distance from the observer where a determination of a conflict with another aircraft can be made.”

The CropCam’s small size and light weight are one of its strengths. However, in terms of the visual line-of-sight requirement it is a major weakness. Per 08-01, the visual observer must maintain visual contact with the CropCam at all times. Even at the minimal altitude of 400 ft AGL the CropCam can be difficult to see. Figure 29 illustrates the difficulties of visually tracking a small UAS even at 400 ft AGL. In the image, the CropCam is the small black dot located in the center, near the bottom of the image. From my experience, any altitude above 1,000 ft AGL for an aircraft similar to the CropCam would be far too high to maintain constant visual contact.

Another factor that we encountered was significant fluctuations of altitude during flight. The CropCam's altitude during flight can fluctuate significantly due to thermal activity and other weather phenomenon. It was determined that the safest altitude we could fly and still stay within our CoA while account for altitude fluctuations was 1,000 ft AGL.

Figure 29. Visual Line of Sight of the CropCam at 400 ft.

During the growing season of 2011 flights were conducted at 400 ft, 600 ft, 800 ft, and 1,000 ft AGL. Images were captured at each of these altitudes and comparisons in area coverage were made. Figure 30 illustrates images representative of each of these heights. After comparison it became quite apparent that 1,000 ft AGL is the optimal height for flight. At this altitude it is possible for a small UAS like the CropCam to image an entire half section. At all other altitudes under 1,000 ft AGL this is not possible due to the requirements of end cover passes. The only major downside to this altitude is that the CropCam becomes very hard to see, which a requirement for safely flying in the NAS. Also, the battery life is greatly reduced due to the high climb the plane must initially make to reach this altitude.

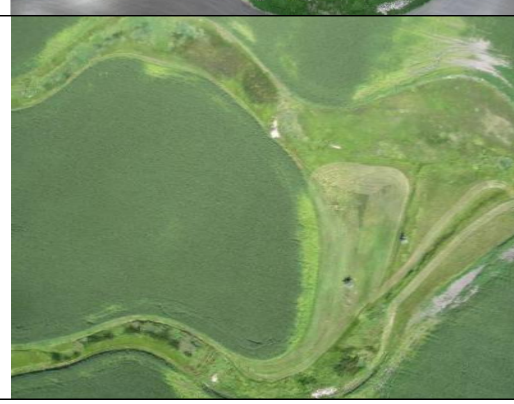
Flying Heights	
400 ft AGL Approximately 2.79 Acres	
600 ft AGL Approximately 4 Acres	
800 ft AGL Approximately 8 Acres	
1,000 ft AGL Approximately 14.22 Acres	

Figure 30. Flying Height and Images.

Another important issue when determining the appropriate altitude for agricultural study using UAS is image overlap. For an image mosaic to be completed there needs to be sufficient overlap in each of the images. It is generally accepted that a forward overlap of 60-70% and a side overlap of 35-40% is acceptable. The reason high percentages of overlap are required is because of the possibility of unsatisfactory ground coverage due to drift and crab.

Drift is the lateral movement of the aircraft from the flight line. This can be caused by pilot error, however, in the case of the CropCam it will almost entirely be caused by the wind. Crab occurs when the aircraft is not oriented with the flight line. This occurs when the aircraft is trying to compensate for the cross wind and the aircraft is oriented into the wind. Crab causes the images to not be aligned with the flight path. If sufficient image overlap is achieved, even with drift or crab, the images can still be mosaiced.

At 400 ft AGL, the images had about 50 forward overlap, just under the acceptable percentage (Figure 31). It was also noticed that due to the low flying height the camera had to take many pictures in rapid succession. The camera had a hard time keeping up with the rapid pace of the image acquisition, especially in the RAW format. It was common for each leg to have one or possibly even two images that were missed because the camera was not done processing the proceeding images. Also, at 400 ft there was no side overlap. To obtain side overlap at this altitude the horizontal legs would need to be very close together, causing the CropCam to have to make extremely wide and clunky turnarounds. To compensate for this, a 400 ft AGL flight path was created that includes a set of forward legs and a set of return legs that run in-between the forward legs. Figure 32 is an illustration of the survey flight pattern at 400 ft AGL created for the CropCam. The red lines represent the forward legs and the yellow lines represent the in-between return legs. Using this pattern it is possible to obtain complete coverage of the field, however, it requires a tremendous amount of post-process. To mosaic all of the images, they have to be sorted into succeeding rows and identifying the correct images for the correct rows is a tedious process because of the small area covered in each image.

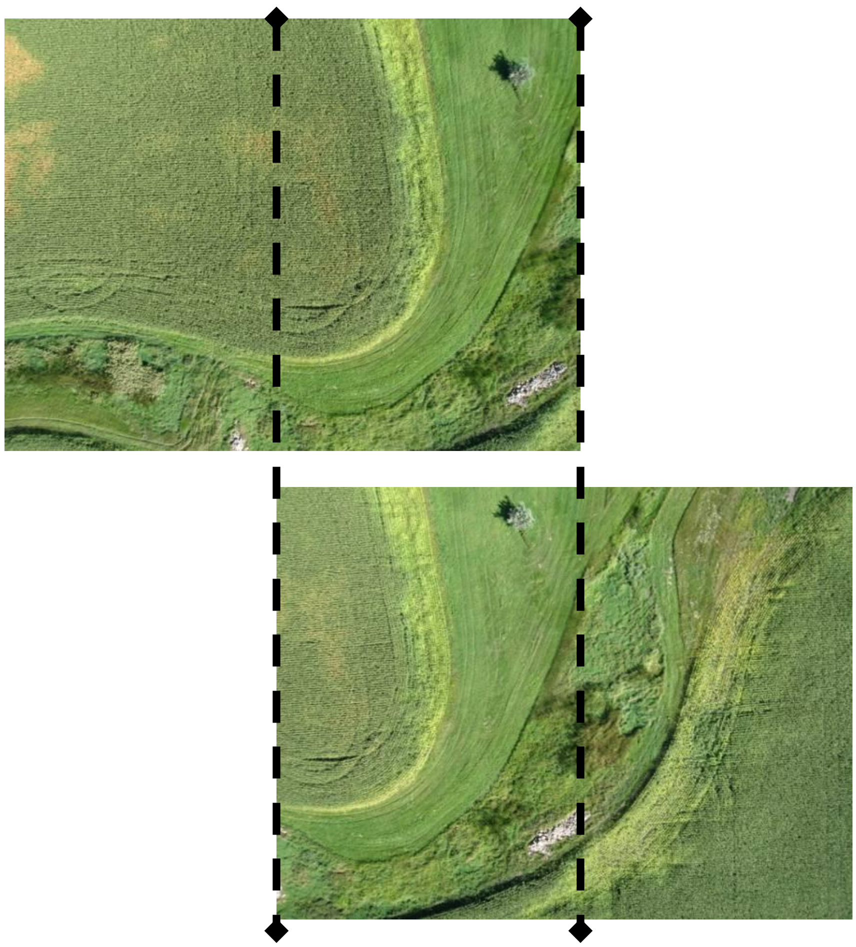


Figure 31. About 50% Forward Overlap for 400 ft AGL Images.

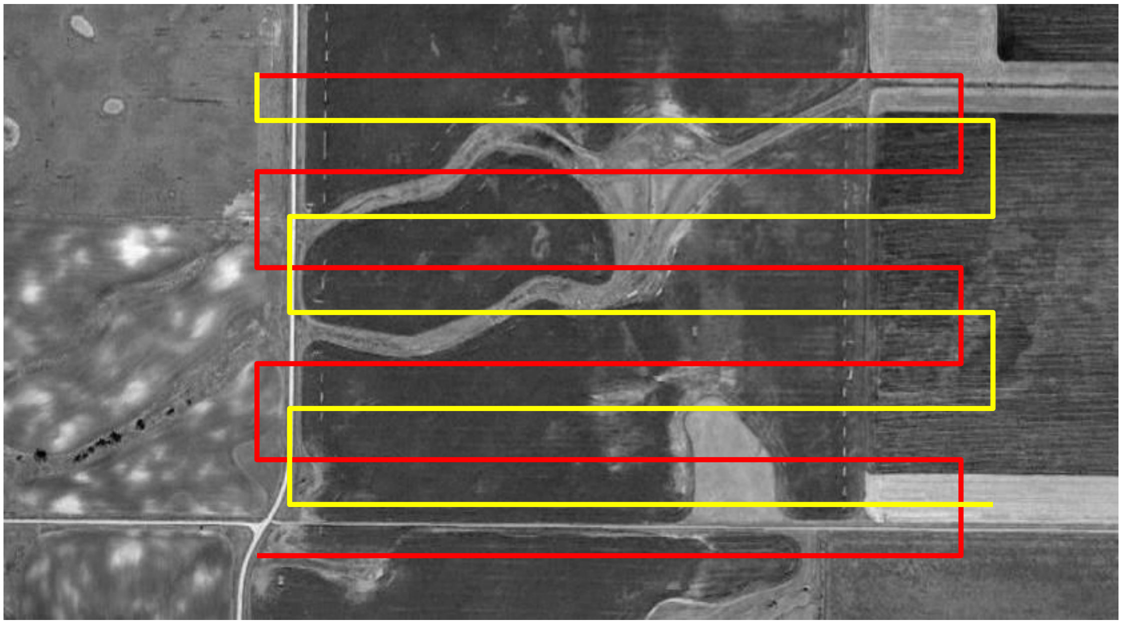


Figure 32. Forward and Return Legs of the 400 ft AGL Flight Path.

At 1,000 ft AGL the images had about 80% overlap and about 80% sidelap (Figure 33 and 34). It was also noted that at this high altitude the cameras never missed an image due to processing time. The RAW file format was never tested at this altitude, however, it is likely that it would not have had any issues processing the images. It is most likely that even if one image was missed that the succeeding image would still contain enough overlap to allow for image mosaicing. At 1,000 ft the ground area of Canon s70 images are almost 15 acres. Due to the enlarged area in each image the legs can be separate farther apart than they are at other, lower altitudes and still maintain sufficient overlap.

During the sixth flying day we tested this theory and we found that it is possible to image an entire half section. A half section is typically what a farmer plants each variety of crops. 1,000 ft AGL is a sufficient altitude to cover this amount of land and still maintain healthy battery life and sufficient image coverage.

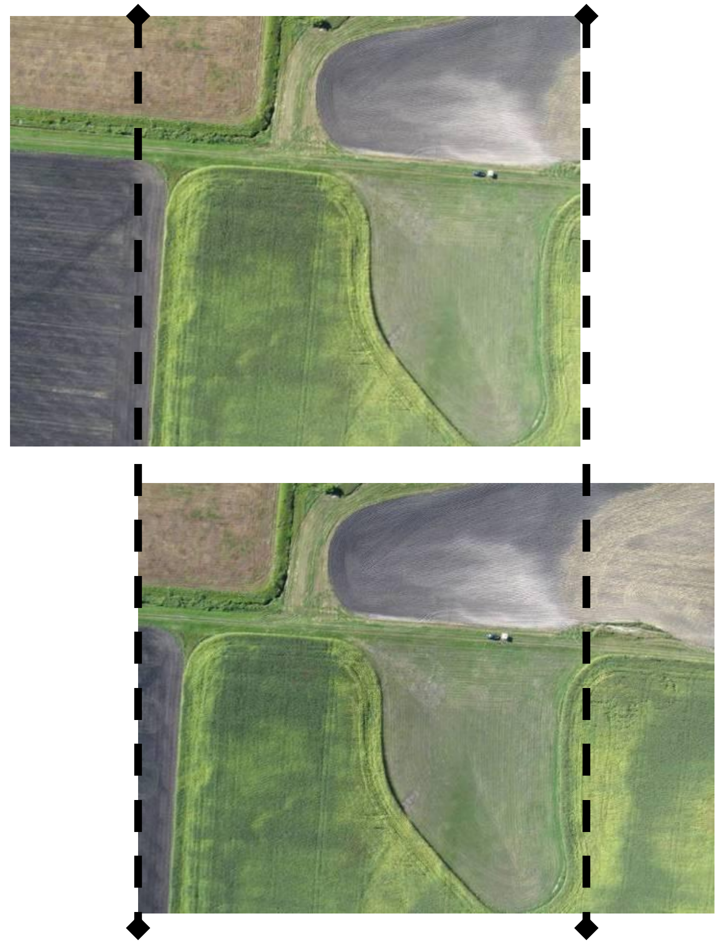


Figure 33. About 80% Forward Overlap at 1,000 ft AGL.

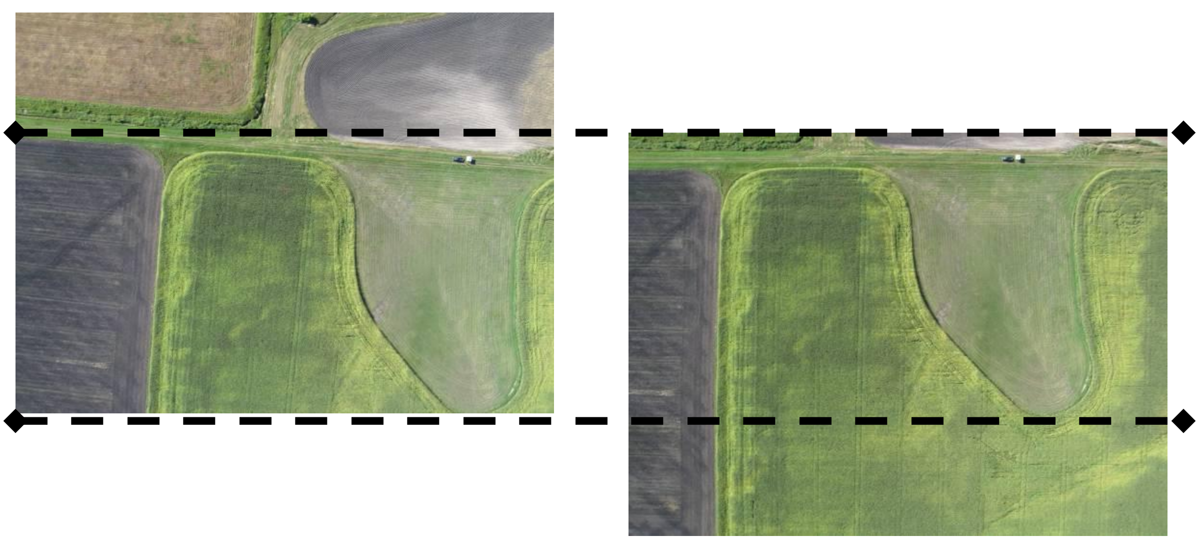


Figure 34. About 80% side overlap at 1,000 ft AGL.

6.2 Issues with Unmanned Aircraft System Using a Point-n-Shoot Cameras

Using an inexpensive, small UAS as a solution for capturing agricultural imagery comes with its own set of challenges. The first flight of this study was used to demonstrate the issues with a CropCam style aircraft for gathering remotely sensed data. Later flights were used to try to mitigate some of these issues. It was found that many of the issues are not correctable without the use of more complicated and expensive sensors or a larger aircraft. A brief discussion of each issued is presented below.

6.2.1 Images are not Georeferenced

The first and one of the most major issues is that the images captured with the CropCam are not georeferenced. This is mainly due to the camera being a closed-system, separate from the aircraft. The images, when downloaded to the computer do not have any georeferencing information. The CropCam's autopilot does record its GPS points throughout the flight. When it snaps an image it records the GPS point. However, the GPS points are not stamped onto any of the images. The GPS points would have to be manually added after the flight from a list of GPS points through the use of geospatial software. These GPS points would probably not serve that much of a purpose because there is only one GPS point and the point is in the middle of the image. Also, the accuracy of the GPS point is imprecise due to the inexpensive GPS and the changes in roll, pitch, and yaw of the aircraft during flight.

During this study, no effort was made to mitigate this issue. There currently is not a small enough sensor or another aircraft similar to the CropCam that can georeference images on-the-go with high accuracy and still stay within the cost constraints of a private farmer. This is something that is beyond the scope of this study and requires the expertise of software and mechanical engineering. The images for this study were georeferenced the using GCPs that were entered using the ERDAS Imagine 2011 software.

Although it is an issue not having the images georeferenced, it should be noted that most satellite images require at least some moderate georeferencing. Most likely, if a farmer is already using satellite imagery he will have experience with georeferencing. Although the geometric correction process is time consuming it is just one limitation that currently accompanies UAS imagery.

6.2.2 Image Mosaic and Overlap Issues

Due to FAA regulations and the restriction in the Flying-S CoA, we could not fly the CropCam high enough to allow for sufficient coverage of the field with one image. This meant that multiple pictures needed to be mosaiced together to form one image of the field. In order for the computer to stitch the images together it was deemed acceptable to have 60-70% overlap and 25-40% side overlap in the images.

The first major problem that I immediately realized was that at 400 feet AGL, almost 114 images would be required to completely cover a half section. This is only if the images are lined up perfectly side-by-side. Accounting for the overlap that is required for a complete image mosaic it would take upwards of 200 plus images. It was also learned that at 400ft, the area footprint is about 2.79 acres. Because of the small footprint, many of the images were completely filled with rows of corn with no distinguishing features. It was almost impossible to locate the exact position of many of the images and would not be possible without looking up the GPS point from the CropCam.

At 1,000 ft AGL many of the issues concerning image mosaicing and overlap are corrected. At this altitude, each image contains about 14.22 acres. If the images were lined up side-by-side it would only take about 23 images to cover a complete half section. Accounting for the overlap, it would only take about 45 images to complete the half section. From our experience, the low-cost image stitching software was able to stitch this many images at 1,000 ft AGL with only minimal user defined GCPs.

6.3 Image Comparison between the Three Different Platforms

It was the objective of the study to capture images of the same area on the same day using all three remote sensing platforms. This did not occur on any occasion throughout the growing season of 2011. However, all three platforms were able to capture usable images within a month of each other (Table 6). This is not the ideal situation for this study but it is the closest approximation to a complete analysis. Although the dates do not correlate enough to allow a very accurate analysis of different vegetation indexes it does allow the comparison of spatial resolutions.

Table 6. Images Used for Image Comparison.

Year	Day	Aircraft	Sensor	Accomplished
2011	30 July	Landsat 5	TM	No
2011	Aug 15	AEROCam	NIR	Yes
2011	Sept 8	CropCam	Canon S70 NIR	Yes

Landsat 5 TM has a spatial resolution of 30 m x 30 m. This means that each pixel in a Landsat scene is 0.22 acres. A Landsat 5 image will display one acre using only five pixels. Each acre is only represented by five distinct values. The AEROCam imagery has a resolution of 1 meter. That means that each pixel is 0.00025 acres. Each acre is represented by over 4,000 pixels. The CropCam imagery has a spatial resolution of 20

cm. That means each pixel is 0.0000099 acres. It would take 101,010 pixels to make up one acre. That means that each acre in the image is represented by over an astounding 100,000 distinct values. The difference in spatial resolution between the three platforms is apparent.

To demonstrate the difference in spatial resolution the following theoretical example is provided. If a farmer planted an acre of beets using the average spacing, 30 inch row spacing and 3 inch seed spacing, he would have about 63,000 beets in one acre. For a Landsat 5 image, that means about 12,600 beets are represented in one pixel. Undoubtedly there will be a lot of variation within that one pixel. However, a Landsat 5 image can only display all that variation as one distinct value. For a CropCam image with the spatial resolution of 20 cm, a pixel would theoretically represent just over half of one beet plant. The astounding difference in spatial resolution is illustrated in the comparison between figure 44 and figure 45. In figure 44, individual rows are easily identified and an area of water damage is clearly seen. In figure 45, which covers the same area as figure 44, only a few shades of green are visible. The increase spatial resolution from the CropCam will help farmers make more accurate decisions. More precision can be applied as individual rows and columns can be targeted instead of large swaths of land.

6.4 Analysis of Water Damage and Planter Issues through Image Comparison

A major area of concern for farmers in the Red River Valley is damage due to standing water. Because of the extremely flat terrain along the valley, drainage is very poor. In many areas, standing pools of water form that prevent crops from growing to maturity. Standing water is easily detectable from the ground, however, identify and analyzing the true context of the water damage can be done best from the air. Satellite images provide valuable information as to the areas of major water damage and possible drainage solutions. However, due to the low temporal resolution of many satellites it is hard to implement any of these changes during the growing season. UAS might allow farmers a real-time image of the water damage and allow them to make changes, if necessary, during the growing season.

Figure 35 is a Landsat 5 image taken on July 30th, figure 36 is an AEROCam image taken on August 15th, and figure 37 is a CropCam image mosaic captured on Sept 8th. These three figures contain image data from the same area in the Flying-S CoA. With the three images side-by-side, the resolution differences are quite obvious. In figure 35 the resolution is too low to accurately assess the water damage to the corn crops. In figure 36, the areas with water damage are clearly seen with the 2-meter resolution of the AEROCam. The high resolution would allow a farmer to analyze the reason for this standing water and create possible mitigation and drainage strategies. In figure 37, the CropCam image mosaic, the water damage can be seen as clearly as with the AEROCam images. The CropCam image mosaic would also allow a farmer to clearly analyze the extent of the water damage.

The unmanned-CropCam image mosaic provides the same, if not better, image quality and information as the high resolution manned-AEROCam images. The benefit of using an UAS is that there is no need for scheduling an outside resource to image the field. Another benefit is that the CropCam images come at a fraction of the cost of manned aircraft imagery. The AEROCam imager is a US$30,000-plus camera while the

CropCam imager cost about US$200. Although the price of the imagers are vastly different the quality of the images are very similar.

Another tool that is used to identify water damage is to view the land with a CIR image. Water has a very low reflectance in the NIR and results in dark or black areas in the image. Figure 38 is a Landsat 5 image using bands 4, 3, and 2, figure 39 is an AEROCam image with NIR, green, and blue bands, and figure 40 is a CropCam image taken using the modified Canon S70 point-n-shoot camera. In all three images, the dark areas are areas of low or no vegetation. Using the modified point-n-shoot Canon S70 camera the areas of water damage can be identified as the dark areas. Although the modified point-n-shoot camera does not produce a true CIR image, the image analysis can still be conducted with very similar accuracy to the AEROCam image.

Figure 35. Landsat Image

Figure 36. AEROCam Image

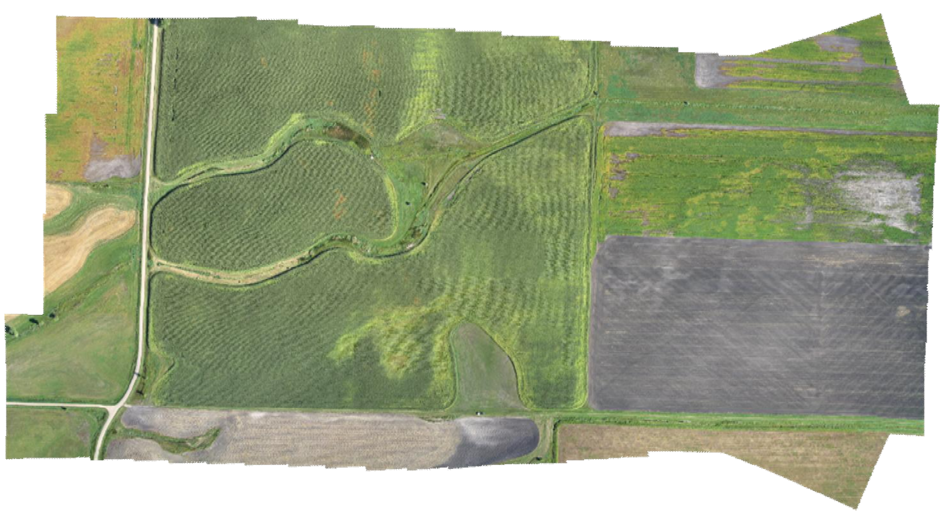


Figure 37. CropCam Image.

Figure 38 Landsat CIR Image.

Figure 39 AEROCam CIR Image.

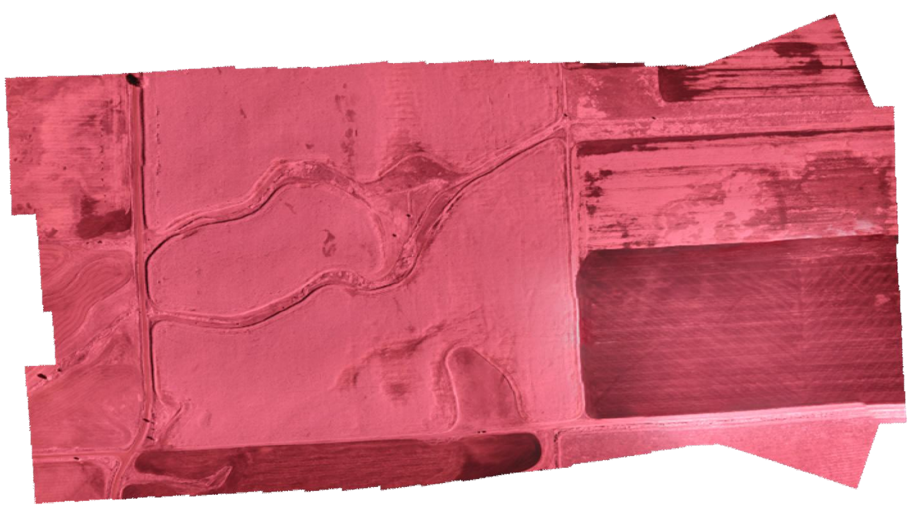


Figure 40. CropCam NIR Image.

Figures 41-43 are Landsat, AEROCam, and CropCam images of an area in the Flying-S CoA that has issues with standing water and machinery skips. In figure 41, the resolution is too low and the pixels are too uniform in color to allow for any significant analysis of what is occurring in the area. Once again, the AEROCam and CropCam images are very similar in the amount of valuable information they provide. In figure 42, the dark patch in the upper-right hand corner is an area of obvious water damage. The area is about an acre in size and sits in the southeast corner of the field. Also, many other black spots can be seen throughout the image indicating areas of high water content. These areas of water damage and high water content can also be seen in the CropCam image mosaic. The area of water damage is clearly visible. Also, there are patches non-vegetated land that are not visible in the Landsat or AEROCam images.

Figure 44 and 45 are close-up images of the machinery skips of both the AEROCam and the CropCam for comparison. Figure 45 is the AEROCam image and because of the 2 meter resolution the planter skips are hardly recognizable. In figure 44, the CropCam Image mosaic, the planter issue is clearly visible along with the tire tracks. You can clearly see the issue with the machinery starting or stopping too early. Although these areas are not vast in extent, they can be used to instruct the operator of the equipment the following year on how to maximize every square inch of the field.

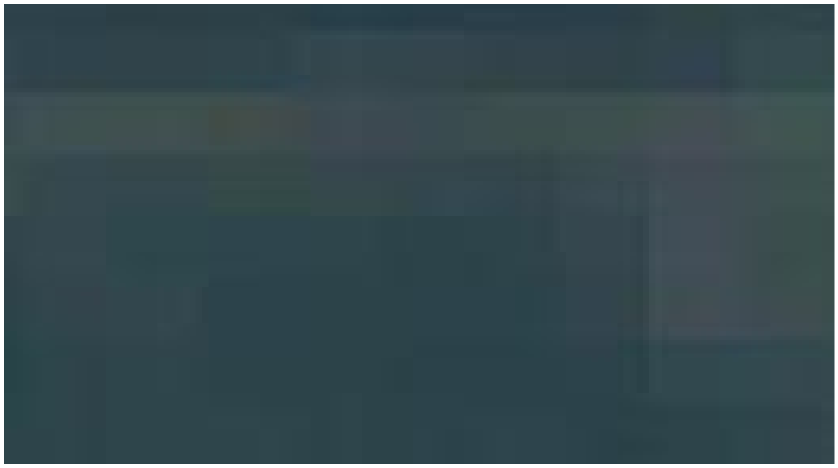


Figure 41. Landsat Water Damage

Figure 42. AEROCam Water Damage

Figure 43. CropCam Water Damage

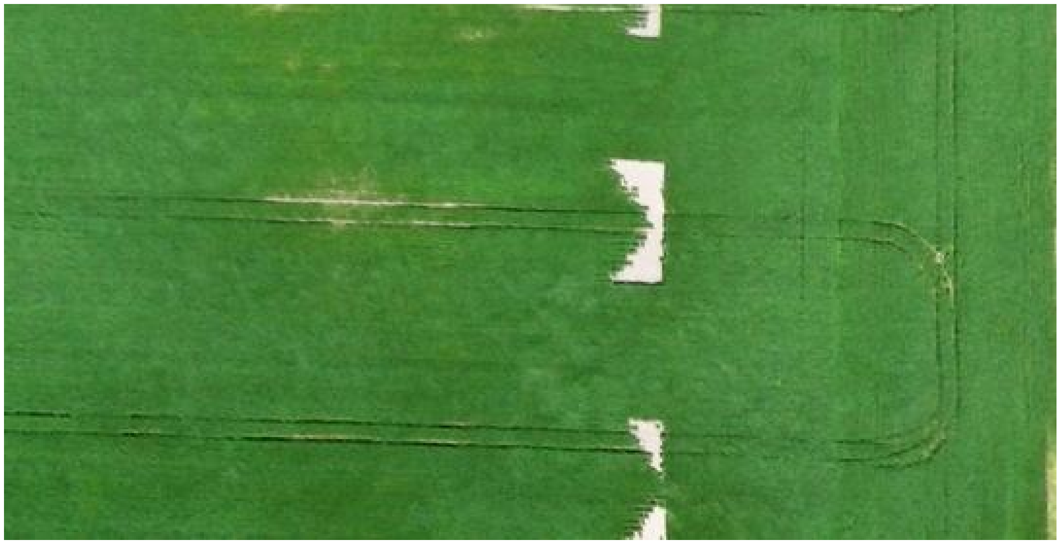


Figure 44. CropCam Close-up.

Figure 45. AEROCam Close-up

Figures 46 and 47 demonstrate the extremely high resolution of the CropCam images. The area of water damage describe in figures 41-43 is highlighted in figure 46. It is clear that this area is almost completely washed out and nothing profitable was produced from this acre of land. Figure 47 is a close-up view that reveals that this area was planted and that all of these seeds have gone to waste. A farmer can use this imagery to make a decision for the future. If there is no reasonable solution for the standing water problem he can learn from these images that it is not profitable to cultivate this land at all.

For example, the average cost of seeds to plant an acre of sugar beets is around US$100. In figure 47, each row can be seen and it is apparent that this area was planted with sugar beet seeds. In this case, the US$100 dollars that was spent on seed was wasted. It also cost an average of US$1,500 in operating costs per acre. These costs include fertilizer, pesticides, gasoline, vehicle depreciation, etc. If the farmer were to consistently cultivate this plot of land and if the water damage continued every year to the same extend he would was about UA$7,500 over a five year period. Using these images from the CropCam, a map could be created to be programmed into the machinery to not cultivate this area of land and save money by reducing waste.

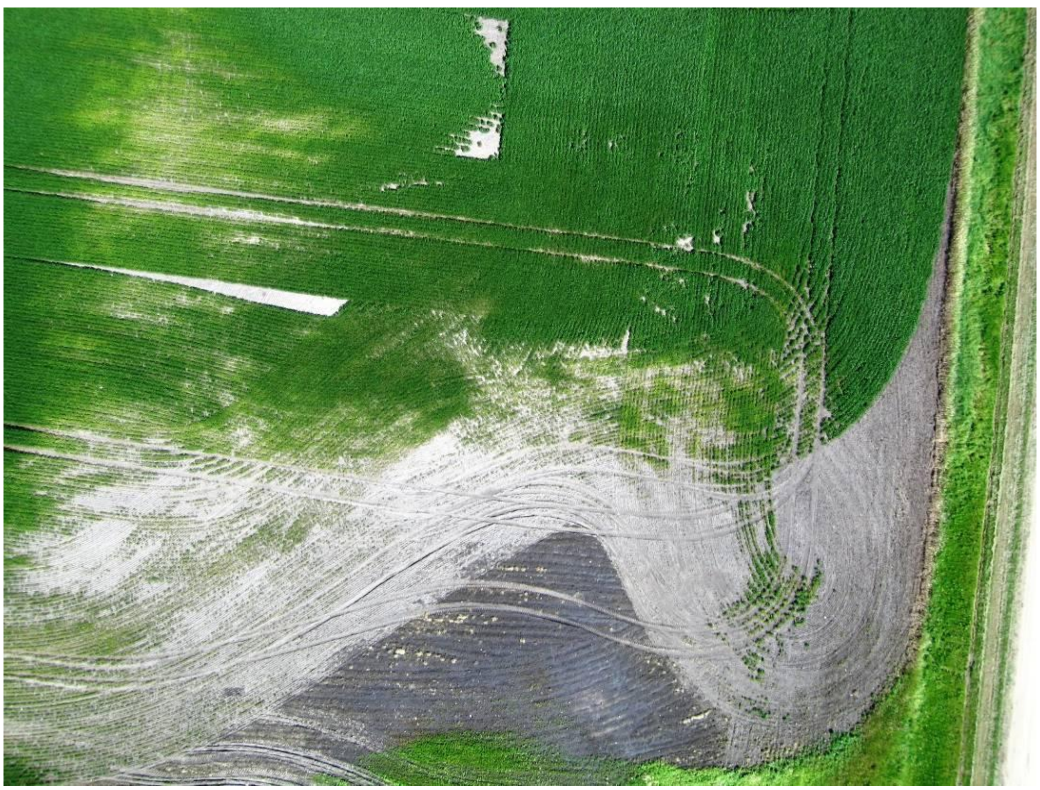


Figure 46. CropCam Water Damage Area.

Figure 47. Individual Rows.

6.5 Legal Conclusions

The current regulatory climate surrounding small UAS in the United States is quite fluid and scheduled for change in the near future. There is currently a lot of opportunity for suggestion on how to safely integrate small UAS into the NAS. Based upon my experience operating a small UAS during the summer of 2011 I have formulated a few suggestions for the safe and timely integration of small UAS into the NAS.

The first, and what I consider to be the easiest and quickest solution, is to allow commercial operations of small UAS to be conducted with regulations similar to that of AC 91-57. Before I continue, I must emphasize that this would only apply to small UAS. A very strong definition, with little wiggle room, would need to be developed to determine if an aircraft is a small UAS in order for this suggestion to work.

Under these new guidelines, small UAS would be allowed to commercially operate less than 400 ft AGL without requiring any kind of prior approval from the FAA. For agricultural purposes, this is not ideal, but it will work. My studies have shown that it is possible to obtain at least a quarter section of a field at 400 ft AGL using a small UAS. However, the CropCam is not the only small UAS in the market and agriculture is not the only industry that is ready to use small UAS. Many applications including, site inspection, mapping, and police work will most the other type of small UAS, a rotary wing or helicopter. These systems, under most circumstances, do not need to operate any higher than 400 ft AGL. It is possible that many commercial applications of UAS could be conducted under 400 ft AGL with great success and stunning results. Also, if this was the official guideline issued by the FAA, companies would begin designing and manufacturing small UAS to complete their required tasks under this standardized altitude.

If for any reason a company wishes to operate their small UAS above 400 ft AGL they would need to apply for a CoA. Because many commercial operations of small UAS can be conducted under 400 ft AGL, this would free up a lot of space for those who need to apply for a CoA to get the attention then need. The office that reviews and approves CoAs would obviously need to be expanded but the access of open airspace below 400 ft AGL would mean that many commercial applications would not require their review or attention.

I believe this new regulatory scheme would be ideal for a number of reasons. Because UAS are so inexpensive, there is going to be an entirely new market of people that will be interested in the technology. This is not something that the manned aviation industry has to deal with. Manned aircraft are expensive and require a special infrastructure for housing and upkeep. They also require special training on how to use. In my opinion, I believe you would be very hard-pressed to find a person that would be willing to step into an airplane of any size and try to operate it without any prior instruction.

This is where unmanned aircraft are very different. Because they are so inexpensive and come in a wide variety of shapes and sizes, they are accessible to almost anyone. Due to these two conditions, people without any prior instruction will be willing to purchase and operate them without any structured training. This situation will make it very difficult to regulate the proper use of small UAS in the NAS. Air traffic will also dramatically increase and if the FAA is required to monitor all of this traffic it would be a heroic feat. However, if there is a segment of airspace 400 ft AGL and below that is free for commercial small UAS operations that should suffice the appetites of many companies while leaving the larger and more complicated tasks to the regulation of the FAA.

The second suggestion and a major requirement that is necessary to make my first suggestion function smoothly is that the CoA process needs to be streamlined. The process is currently a cumbersome and mind-numbing task that requires hours of detailed explanations about theoretical situations. The FAA is responsible for the safety of Americans in the sky and the detailed CoA explanations ensure this safety. However, my suggestion is to create a 'frequent user' designation that contains a 'fast pass'. This process would be similar to what many hotel and car rental companies have today for speedy and hassle-free service for their frequent customers.

Companies and organizations that frequently use small UAS could apply for a 'fast pass'. The application for this pass will require the company to provide all of the detailed explanations required in the CoA process, plus information concerning pilot training and other special circumstance that prove they are experts in the field of small UAS and can consistently operate small UAS in the NAS without accident or loss of life.

The ‘fast pass’ does not mean the company is exempt from filing for a CoA when it desired to conduct a mission with a small UAS above 400 ft AGL. The ‘fast pass’ is to show the CoA reviewer that this company has already proven worthy of conducting operations safely in the NAS and only needs to provide a brief description of the mission details. To keep companies honest, the ‘fast pass’ will need to be reevaluated on a two year basses to make sure the company has not had any accidents or incidents that demonstrated its unworthiness of the ‘fast pass’.

The FAA is currently working on a proposal for how they will integrate small UAS into the NAS. I believe my suggestions could help speed up the process by allowing a large chunk of commercial UAS to occur in airspace that has already been designated for aircraft of this size for decades. The streamlined CoA process will help to make sure small UAS operations are conducted safely and without delay due to paperwork requirements.

CHAPTER VII

FUTURE WORK

The first future work that needs to be conducted is to use the CoAs that were received to fly over farmers fields. The optimal situation would be to try and simulate the actual conditions of a privately owned and operated UAS. The situation would include a farmer identifying an area of his field that has some sort of condition that needs further study. The farmer would call UND and a team would be sent to his fields as-soon-as-possible to image that area. The farmer then could look at the images and make decisions on his future direction for that area. If a study like this were conducted it would be possible to have actual dollar amounts to the usefulness of the technology.

Another possible study would be to conduct a market survey of the potential acquisition of UAS technology. Satellite imagery has taken a long time to become integrated into modern agriculture and UAS technology might find a similar story. A market survey could be conducted to find out how many farmers use satellite imagery, what they would be willing to pay for a UAS system, and if they even see the technology as potentially useful.

Another study would be to fly on a day when a high resolution satellite takes imagery. These satellite images would need to be purchased. The next step would be to evaluate that NDVI images of the CropCam and the high resolution satellite images.

APPENDICES

Flight Report

Date	18-Sep-10			
Location	Flying-S			
Weather Conditions	Temp:	32 degrees F	Clouds:	Partly cloudy
	Wind:	7 mph; gust to 10 mph	Time:	10:15-1:21 pm

Purpose

The purpose of the first flying day was to familiarize myself (Jeremy Smith) with the CropCam airframe, the ground control station software, gather color images with the Pentax camera at 400 ft and 800ft, better understand the capabilities and limitations of the CropCam system and identify possible solutions to use during the next growing season.

Flights

Flight 1		400 ft AGL
Camera Settings	**Camera Pod 1**	Pentax Optio: JPEG: RGB
	Camera Pod 2	N/A
Data Recorded	59 images	
Notes	The CropCam only relayed an E/W GPS coordinate and did not relay a N/S GPS coordinate. The CropCam was receiving a N/S GPS coordinate because it was flying the path correctly	
Flight 2		800 ft AGL
Camera Settings	**Camera Pod 1**	Pentax Optio: JPEG: RGB
	Camera Pod 2	N/A
Data Recorded	None	
Notes	After launch, the CropCam lost forward movement. The PIC took manual control of the aircraft and increased airspeed. After a couple of exchanges the PIC manually land the CropCam.	
Flight 3		800 ft AGL
Camera Settings	**Camera Pod 1**	Pentax Optio: JPEG: RGB
	Camera Pod 2	N/A
Data Recorded	51 images	
Notes	Winds increased to 15 mph. Experience significant variations in altitude throughout flight. Airspeed increased to combat but to no effect. Airspeed was lowered to 33 knots to conserve battery life.	

Results and Conclusions

Images are not georeferenced. GPS on CropCam will likely be inaccurate due to variations of roll, pitch and yaw during flight. No overlap at 400 ft and only minimal overlap at 800 ft. The flight path will have to be modified for greater overlap for image mosicing. Images were blurry.

Flight Report

<table>
<tr><td>Date</td><td colspan="4">11-June-11</td></tr>
<tr><td>Location</td><td colspan="4">Flying-S</td></tr>
<tr><td rowspan="2">Weather Conditions</td><td>Temp:</td><td>50 F</td><td>Clouds:</td><td>Clear skies</td></tr>
<tr><td>Wind:</td><td>5 mph; gust to 7 mph</td><td>Time:</td><td>10:45-1:45 pm</td></tr>
<tr><td colspan="5">Purpose</td></tr>
<tr><td colspan="5">The purpose of the flight is to test the new camera pods for the additional weight of the new Canon Cameras. Flight will be conducted with ballast weights to test for safety. Once safe, flights will be conducted with the Canon cameras installed and taking images in both RGB and NIR in Raw data format.</td></tr>
<tr><td colspan="5">Flights</td></tr>
<tr><td colspan="2">Flight 1/2</td><td colspan="3">600 ft AGL – Figure 8 Pattern</td></tr>
<tr><td rowspan="2">Camera Settings</td><td>Camera Pod 1</td><td colspan="3">None</td></tr>
<tr><td>Camera Pod 2</td><td colspan="3">None</td></tr>
<tr><td>Data Recorded</td><td colspan="4">None</td></tr>
<tr><td>Notes</td><td colspan="4">CropCam experienced a tip-stall on the first right turn of the figure-8 pattern. PIC took control and landed the aircraft safely. Airspeed was increased for second flight and completed it safely.</td></tr>
<tr><td colspan="2">Flight 3</td><td colspan="3">800 ft AGL</td></tr>
<tr><td rowspan="2">Camera Settings</td><td>Camera Pod 1</td><td colspan="3">Canon S70: CRAW: RGB</td></tr>
<tr><td>Camera Pod 2</td><td colspan="3">Canon S70: CRAW: NIR</td></tr>
<tr><td>Data Recorded</td><td colspan="4">40 RGB & 40 NIR</td></tr>
<tr><td>Notes</td><td colspan="4">Upon landing the left wing tip caught some tall grass which spun the plane. The starboard camera pod took the brunt of the landing and was shattered. Both cameras survived the landing.</td></tr>
<tr><td colspan="2">Flight 4</td><td colspan="3">800 ft AGL & 400 ft AGL</td></tr>
<tr><td rowspan="2">Camera Settings</td><td>Camera Pod 1</td><td colspan="3">Canon S70: CRAW: RGB</td></tr>
<tr><td>Camera Pod 2</td><td colspan="3">None</td></tr>
<tr><td>Data Recorded</td><td colspan="4">53 images</td></tr>
<tr><td>Notes</td><td colspan="4">800 ft AGL on the away legs and 400 ft AGL on the return legs. Tests the flight commands from the GCS and the CropCam was extremely responsive.</td></tr>
<tr><td colspan="5">Results and Conclusions</td></tr>
<tr><td colspan="5">CropCam experience a significant changes in altitude from thermal activity. Leave a safety buffer 200 ft below the ceiling of the CoA. The camera pods need to be constructed out a material that is stronger than balsa wood. There was also a controller failure that was fixed with the MP Vision.</td></tr>
</table>

Flight Report

<table>
<tr><td>Date</td><td colspan="4">16-June-11</td></tr>
<tr><td>Location</td><td colspan="4">Flying-S</td></tr>
<tr><td rowspan="2">Weather Conditions</td><td>Temp:</td><td>75 F</td><td>Clouds:</td><td>Clear skies</td></tr>
<tr><td>Wind:</td><td>0 mph; gust to 5 mph</td><td>Time:</td><td>12:30 pm</td></tr>
<tr><td colspan="5">Purpose</td></tr>
<tr><td colspan="5">The purpose of this flight was to use the Pentax Optio and the Canon S70 side-by-side and determine which camera records the best images with the widest angle. It was intended that flights would be conducted at 400, 800 and 1,000 ft. However due to technical problems with radar tracking equipment only one flight was conducted.</td></tr>
<tr><td colspan="5">Flights</td></tr>
<tr><td colspan="2">Flight 1</td><td colspan="3">400 ft AGL</td></tr>
<tr><td rowspan="2">Camera Settings</td><td>Camera Pod 1</td><td colspan="3">Pentax Optio: JPEG: RGB</td></tr>
<tr><td>Camera Pod 2</td><td colspan="3">Canon S70: JPEG: RGB</td></tr>
<tr><td>Data Recorded</td><td colspan="4">130 Canon & 80 Pentax</td></tr>
<tr><td>Notes</td><td colspan="4">Flew the survey pattern. The clouds were really low so 400 ft AGL was determined to be the safest altitude.</td></tr>
<tr><td colspan="2">Flight 2</td><td colspan="3">--</td></tr>
<tr><td rowspan="2">Camera Settings</td><td>Camera Pod 1</td><td colspan="3">--</td></tr>
<tr><td>Camera Pod 2</td><td colspan="3">--</td></tr>
<tr><td>Data Recorded</td><td colspan="4">--</td></tr>
<tr><td>Notes</td><td colspan="4">--</td></tr>
<tr><td colspan="2">Flight 3</td><td colspan="3">--</td></tr>
<tr><td rowspan="2">Camera Settings</td><td>Camera Pod 1</td><td colspan="3">--</td></tr>
<tr><td>Camera Pod 2</td><td colspan="3">--</td></tr>
<tr><td>Data Recorded</td><td colspan="4">--</td></tr>
<tr><td>Notes</td><td colspan="4">--</td></tr>
<tr><td colspan="5">Results and Conclusions</td></tr>
<tr><td colspan="5">The major lesson of the trip was that the more equipment that higher likelihood of failure. The UND radar trailer was brought along for this trip to capture radar data. It took almost three hours to get all of the equipment set up and running correctly, leaving us time for only one flight.</td></tr>
</table>

Flight Report

Date	17-July-11			
Location	Flying-S			
Weather Conditions	Temp:	50 F	Clouds:	Overcast
	Wind:	15 mph; gust to 20 mph	Time:	12:30 pm

Purpose

The purpose was to collect images at 400 ft AGL using the Canon Camera to shoot in JPEG for one flight and RAW in the second. The modified survey pattern from the previous flying day was used.

Flights

Flight 1		400 ft AGL
Camera Settings	**Camera Pod 1**	Canon S70: JPEG: RGB
	Camera Pod 2	Canon S70: RAW: RGB
Data Recorded	100 RGB & 90 NIR	
Notes	The high wind speeds	
Flight 2		--
Camera Settings	**Camera Pod 1**	--
	Camera Pod 2	--
Data Recorded	--	
Notes	--	
Flight 3		--
Camera Settings	**Camera Pod 1**	--
	Camera Pod 2	--
Data Recorded	--	
Notes	--	

Results and Conclusions

The high wind speeds caused many of the images to be very blurry. The CropCam overshot all of the turns and would “crab” while it was flying the legs. On many of the legs NIR images were not captured. This is most likely the result of a difference of settings on the cameras.

Flight Report

Date	06-Aug-10			
Location	Flying-S			
Weather Conditions	Temp:	80 F	Clouds:	Partly cloudy
	Wind:	0 mph; gust to 3 mph	Time:	12:00 – 1:49 pm

Purpose

The purpose was the gather images at 400 ft, 600 ft, and 1,000 ft AGL with the Canon S70 cameras shooting in the NIR and RGB.

Flights

Flight 1		400 ft AGL
Camera Settings	**Camera Pod 1**	Canon S70: JPEG: RGB
	Camera Pod 2	Canon S70: JPEG: NIR
Data Recorded	64 RGB & 83 NIR	
Notes	A crop duster flew directly into our airspace during the flight. PIC moved the CropCam. The disturbance meant that we didn't have enough battery to finish to flight pattern	
Flight 2		1,000 ft AGL
Camera Settings	**Camera Pod 1**	Canon S70: JPEG: RGB
	Camera Pod 2	Canon S70: JPEG: NIR
Data Recorded	85 NIR & 85 RGB	
Notes	The batteries are getting old and drain really fast.	
Flight 3		600 ft AGL
Camera Settings	**Camera Pod 1**	Canon S70: JPEG: RGB
	Camera Pod 2	Canon S70: JPEG:NIR
Data Recorded	82 RGB & 80 NIR	
Notes	--	

Results and Conclusions

Aircraft appear very quickly so the observer must be very alert. Batteries must be monitored during flight so as to make sure there is enough juice to complete the flight pattern; especially when the batteries are old.

REFERENCES

Aerovironment. (2012). UAS: Raven.

AP. (2012). Congress OKs bill to update U.S. air control system. http://www.usatoday.com/news/washington/story/2012-02-06/Air-Control-Bill-Congress/52993758/1.

Astronautix. (1999). Pathfinder.

Campbell, J. B.. (2002). Introduction to Remote Sensing (3rd Ed.) The Guilford Press.

CropCam. (2011).

Curry, J. A., J. Maslanik, G. Holland, J. Pinto. (2005). Applications of Aerosondes in the Atrtic. Bulletin of the American Meterologic Society. December. 1855-1861

Deptula, D. A., J. R. Marrs. (2009). Global Distributed ISR Operations: The Changing Face of Warfare. National Defense University: Institute for National Strategic Studies.

Grenzdorffer, G. J., A. Engel, B. Teichert. (2009). The Photogrammetric Potential of Low-Cost UAVs in Forestry and Agriculture. 1207-1213.

Hardin, J. P., R. R. Jensen. (2011). Small-Scale Unmanned Aerial Vehicles in Environmental Remote Sensing: Challenges and Opportunities. GIScience and Remote Sensing. v. 48, no. 1; 99-111.

Holland, G., J. Curry, G. Tyrrell. (2003). The Aerosonde Environmental Observing Platform.

Jensen, J.R. (1996). Introductory digital image processing: a remote sensing perspective. Englewood Cliffs, New Jersey: Prentice-Hall.

Jensen, J.R. (2007) Remote Sensing of the Environment: an Earth Resources Perspective. Prentice Hall.

Jensen, A. M., M. Baumann, Y. Q. Chen. 2009. Low-Cost Multispectral Aerial Imaging Using Autonomous Runway-Free Small Flying Wing Vehicles.

John Deere. (2012).

Johnson, L. F., S. Herwitz, S. Dunagan, B. Lobitz, D. Sullivan, & R. Slye. (2003). Collection of Ultra High Spatial and spectral resolution image data over California vineyards with a small uav. International Symposium on Remote Sensing of Environment.

NASA. (2011). NASA Helios Fact Sheet.

NASA. (2008). Dryden flight research center. Pathfinder solar-powered aircraft.

NASA. (2012). Earth Observatory.

Nebiker, S. A. Annen, M. Scherrer, D. Oesch. (2008). A Light-Weight Multispectral Sensor For Micro UAS – Opportunities for Very High Resolution Airborne Remote Sensing.

Newcome, L.R. (2004). Unmanned Aviation: a brief history of unmanned aerial vehicles. American Institute of Aeronautics and Astronautics, Inc. Reston, Virginia.

Peterson, M. E. (2006). The UAV and the Current and Future Regulatory Construct for the Integration into the National Airspace. Journal of Air Law and Commerce. v. 71; 535-615.

Pinter, P. J.. (2003). Remote Sensing for Crop Management, Photogrammetric Engineering and Remote Sensing. June. 647.

Popular Mechanics. (1954). Brightly colored “fish” fly high over New Mexico’s sand dunes. January. 105.

San Diego Air and Space Museum. (2012). The Ryan Firebee.

Seelan, S. K., D. Baumgartner, G. M. Casady, V. Nangia, G. A. Seielstad. (2007). Empowering farmers with remote sensing knowledge: A success story from the US Upper Midwest. Geocarto International. 22; 2.

Seelan, S. K., S. Laguette, G. M. Casady, G. A. Seielstad. (2003). Remote Sensing Applications for Precision Agriculture: A Learning Community Approach. Remote Sensing of Environment, 88; 157-169.

Spaceref. (2001). NASA to fund two UAV science demonstration missions.

Wiegand, C.L., A. J. Richardson, D. E. Escobar, A.H. Gerbermann. (1991). Vegetation indices in crop assessments. Remote Sensing of Environment. 25; 2-3. 105-119.

Xiang Haitao and Lei Tian. (2010). Development of a low-cost agricultural remote sensing system based on an autonomous unmanned aerial vehicle (UAV). Biosystems Engineering. 108; 2.

Zhang, X., S. Lijian, X. Jia, G. Seielstad, C. Helgason. (2009). Zone mapping application for precision-farming: a decision support tool for variable rate application. Precision Agriculture.